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PREPARED BY

MILITARY OPERATIONS RESEARCH DIVISION
LOCKHEED AIRCRAFT CORPORATION
CALIFORNIA DIVISION • BURBANK, CALIFORNIA

FOR

OFFICE OF NAVAL RESEARCH
AIR BRANCH

(6) AIRBORNE DISTANT EARLY WARNING SYSTEMS FOR 1960 TO 1965 (8)

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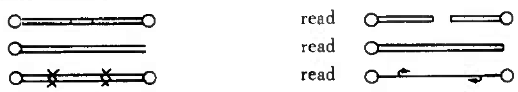
ERRATA

Foreword, p. viii — for R. W. Conklin read R. H. Conklin

Summary, p. xvi — Figure S.1. In Barrier Tactical Models, Section titled Patterns, diagrams should appear as follows:

for / read



p. xxi — Under Selection of Best Systems — MT1 Not Available for $290 millions read $301 millions

Chapter I, p. 15 — Figure I .2. In Barrier Tactical Models, Section titled Patterns, should appear as in Figure S.1, above.

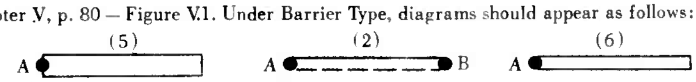
Chapter IV, p. 70 — Figure IV.4, equations should appear as follows:

Barrier Nos. 1, 3, 5: for $(\frac{D}{S} + 1)$ read $\left(\frac{D}{S} + 1\right)$

Barrier Nos. 2, 4, 6: add long parens to expressions following $\phi\ \frac{D}{S}$

p. 74 — Under Helicopter Force Requirements. In Equation, T_S, delete endurance.

Chapter V, p. 80 — Figure V.1. Under Barrier Type, diagrams should appear as follows:



Chapter VI, p. 119 — Equations at bottom of page should be read to include C_B, as in word equation, center of same page.

p. 123 — Remove underscore, first line.

p. 125 — Figure VI.2. For 7 x 7.5′ read 27 x 7.5′. Transpose Level 1 and Level 2.

p. 125 — Figure VI.3. Transpose Level 1 and Level 2.

p. 126 — Figure VI.4, fourth column. For attain read attained.

p. 129 — Under Altitude. For endurance read time on station.

p. 133 — Figure VI.11, under ML. For 38,000 read 3800.

p. 133 — Figure VI.12, for Endurance read Time on Station.

p. 135 — Under Comparison of Barrier Component Costs, third line from bottom of page. For Figure VI.20 read Figure VI.16.

p. 137 — Figure VI.17, footnote. Delete UHF

Chapter VII, p. 147 — Under Introduction, 2nd Paragraph. For from read form.

p. 165 — Figure VII.5, for V read ¥.

p. 168 — Figure VII.19, Airship Volume read ¥ before = signs.

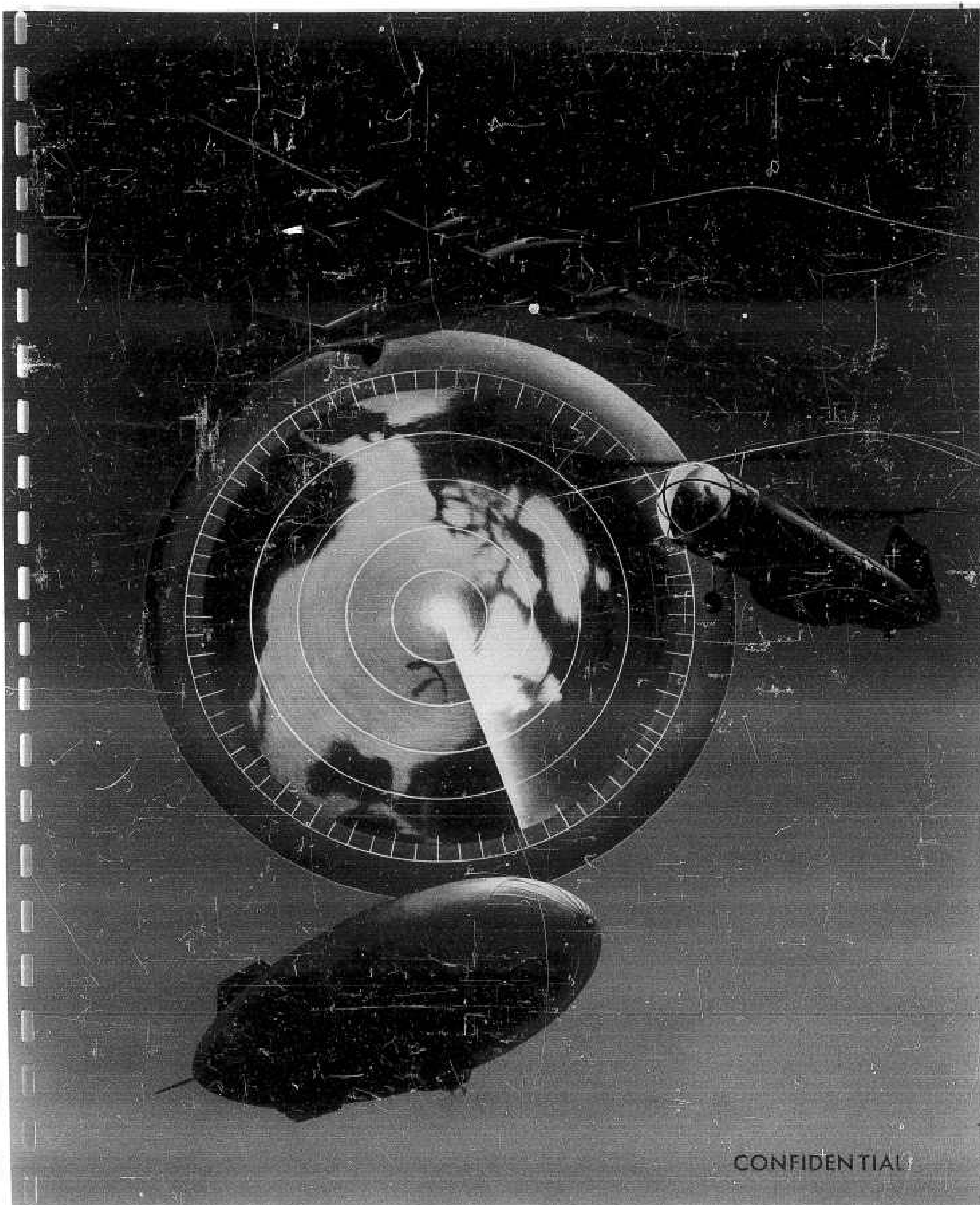
Chapter VIII, p. 179 — Figure VIII.5, bottom right-hand column, System Cost. For 290 read 301.

Appendix A, p. 195 — Line 6. For 1.0 read 1.9.

p. 198 — 2nd paragraph, first sentence. For Figures A.7a and A.7b read Figure A.8. 2nd sentence. For these graphs read this graph.

p. 201 — Figure A.8. For Montauk-Highlands code symbol should be ⊙.

Glossary — T_S, Delete Endurance.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FOREWORD

This report presents the results of a study to determine optimal characteristics for barrier type airborne early warning systems. These systems are designed for use against air-breathing targets and could become operational during the period 1960-1965.

In October, 1954, an oral progress report was made to representatives of CNO, BuAer and ONR, in order to review the scope and assumptions of the study for interested groups. This progress report provided an opportunity for those who might wish to influence the course of the work before the process of detailed analysis and evaluation was begun. Later in the month the same oral report was presented to members of Project LAMP LIGHT, at Lexington, Massachusetts, in order to gain the benefit of the opinion which might be elicited.

A preliminary review of the study, methodology and results was held in March, 1955, in Burbank, California. The review committee consisted of members of CNO, BuAer, ONR, NADU (South Weymouth), NRL and the Lincoln Laboratory.

The Military Operations Research Division feels that the considerable amount of outside comment and constructive criticism gained from these oral reports and reviews has contributed materially to the value of the study. It has been necessary to enter areas in which little or no data exist on the subject in question. For this reason, the extension of discussion to outside groups working along similar lines is of great value; and this Division wishes to acknowledge the assistance of all the groups which contributed to this effort.

There are six supplementary memorandum reports, each dealing with a specialized phase of the analysis, which support the assumptions, results and conclusions appearing in

this Summary Report. These supporting documents may be requested from the Air Branch, Office of Naval Research. They are identified as follows:

Memorandum Report No.	Title	Author
7089	The Analysis of Airborne Radar, *1 July 1955.*	W. W. Lindsay, Jr. and G. A. Korn
7090	Early Warning Airplane Parametric Analysis, *1 July 1955.*	R. W. Allen
7091	Early Warning Helicopter Parametric Analysis, *1 July 1955.*	J. F. H. Bertucci and R. W. Allen
7092	Early Warning Airship Parametric Analysis, *1 July 1955.*	D. W. Baxter
7093	Cost Analysis for Airborne Early Warning Barrier Systems, *1 July 1955*	R. W. Conklin
7094	Communications and Navigation in Airborne Early Warning Barriers, *1 July 1955.*	A. G. Bogosian and E. S. Quilter

Burbank, California
1 July 1955

Robert A. Bailey, Director
Military Operations Research Division
Lockheed Aircraft Corporation

ACKNOWLEDGMENTS

This report was prepared under the general supervision of Mr. Sherwood C. Frey, Department Manager for Navy Studies, and under the direction of Mr. Robert G. Gibson.

Acknowledgment is due the Goodyear Aircraft Corporation for its valuable work on the airship parametric study, and to Bell Aircraft for its contributions on helicopter problems.

Recognition should be made of the following members of MORD who have contributed to the research and production of this and the supporting reports:

Mr. Ralph W. Allen	Airplane Analysis
Mr. Dale W. Baxter	Military Loads, Airship Analysis
Mr. John F. H. Bertucci	Helicopter Analysis, Tactical Models
Mr. Corlin O. Beum, Jr.	Human Engineering, Air Defense Environment
Mr. Ares G. Bogosian	Navigation, Communications
Mr. Roland H. Conklin	Cost Methods
Mr. Richard E. Falconer	Editorial
Mr. Thomas P. Higgins, Jr.	Air Defense Environment
Mr. Donald L. James, Jr.	Aeronautical Analysis
Dr. Granino A. Korn	Search Theory
Mr. John E. Laurance	High Energy Fuels, In-Flight Refueling
Mr. William W. Lindsay, Jr.	Radar, Communications
Mr. Byron L. Pierce	Art and Production
Mr. Edward S. Quilter	Tactical Models, Communications, In-Flight Refueling, Military Loads
Dr. William C. Randels	Defensive Missiles
Mr. John A. Smithson	Radar
Dr. John E. Walsh	Mathematical Analysis
Mr. Hobart R. Yeager	Electronics, Air Defense Environment

TABLE OF CONTENTS

SUMMARY

THE PROBLEM

Late in 1953 the Office of Naval Research requested the Military Operations Research Division to perform a study of airborne early warning (AEW) systems for continental defense of the United States during the period 1958 to 1962.

The task order listed objectives of the study as follows:

"(1) To comprehensively analyze the problem of integrating the airborne AEW and ASW (Anti-Submarine Warfare) efforts into the Continental Air Defense System.

"(2) To determine the characteristics of optimal airborne weapon systems which could become operational by 1960.

"(3) To develop a measure of effectiveness permitting selection of optimal airborne systems. This also will provide for comparisons of lighter-than-air and heavier-than-air weapon systems performing air defense missions."

Shortly after the task assignment was received from ONR it became clear that the Navy was to be given responsibilities for implementing and maintaining sea wing barriers to provide early warning of penetrating aircraft. The objectives of the study were accordingly oriented to cover this mission. In addition, the problems inherent in combined AEW-ASW operations were examined. It became apparent immediately that, although air, surface and subsurface surveillance operations have common objectives, the equipment and tactics required for the three functions might well differ markedly. The decision was made to leave the problem of integrations of these functions at rest until further knowledge of AEW had been acquired. The principal effort in this analysis was, therefore, concentrated on the problem of air surveillance.

In examining the broad problem, the study group was assisted toward a definition of the scope by consideration of the various military situations in

which Distant Early Warning (DEW) systems could be of value. These are (1), a situation containing the characteristics of a cold war, as at present; (2), a period characterized by transition from the cold to the hot war phase; and (3), the hot war itself. It is possible, within manageable bounds, to set forth the conditions comprising the cold war situation; but in order to analyze the hot war, and possibly the transition phase as well, the entire continental defense posture must be considered. Any effective analysis of this large environment must be constructed on the knowledge of its components. The best solution appeared to consist of the following; first, to analyze in detail the cold war situation and to optimize aircraft for use under such conditions; second, to determine the additional capabilities that might be required during the transition and hot war phases and to study their effects on the aircraft previously optimized.

SPECIFIC OBJECTIVES OF THE STUDY

The specific objectives of the study are:

1. To determine, for both distant early warning (DEW) and distant early warning and control (DEW & C).

    a. the best airplane system;
    b. the best helicopter system;
    c. the best airship system.

2. To select the best airborne early warning system.

ASSUMPTIONS

Three basic assumptions are made:

1: The primary purpose of the barrier line is early warning of penetrating aircraft and does not include trailing or closing unknown targets.

2. The 1960 threat is that designated in the Joint Intelligence Committee estimates. The primary threat assumed is the Type 37 high performance jet bomber equivalent to the B-52. In addition, it is assumed that the enemy will have in significant numbers the

Type 39, equivalent to the B-47, as well as TU-4's, the Type 31 turboprop, and pilotless aircraft.

3. Radar coverage from sea level to the maximum altitude expected for air breathing engines is a design objective, using a single airborne vehicle whether it be airplane, helicopter, or airship.

SCOPE OF THE ANALYSIS

The scope of the analysis is shown in Figure S. 1. Three types of aircraft were considered as vehicles for carrying the weapon system. Possible variations in the system included several types of radar, radar performance and methods of defense. All practical types of barriers and bases were considered as well as tactical models for employment of the vehicles.

The result of considering these many factors is generation of a large number of possible weapon systems as candidates for the optimal solution to the early warning problem. As an example, the dotted line indicates a possible combination of the helicopter in a distant early warning mission, carrying a UHF radar, based upon a merchant vessel spaced for a degraded radar performance level, in a 2000-mile barrier.

In addition to the major factors, many possible design parameters for the aircraft itself are considered. These basic parameters include range, speed, military load, power plant, flight altitude, and many others. The design parameters which are investigated, as well as the manner in which they are used, are discussed in Chapters V, VI, and VII for the airplane, helicopter and airship respectively. The range of values is summarized in Figure S.2.

Measure of Effectiveness

In order to determine which of the many possible aircraft systems is best a measure of effectiveness must be applied to each. The prime objective of early warning barriers is to provide a certain level of detection. Each method for obtaining this level of detection requires a certain amount of the military budget. In this report the general measure of effectiveness is the total cost to the U.S. necessary to attain a given level of detection.

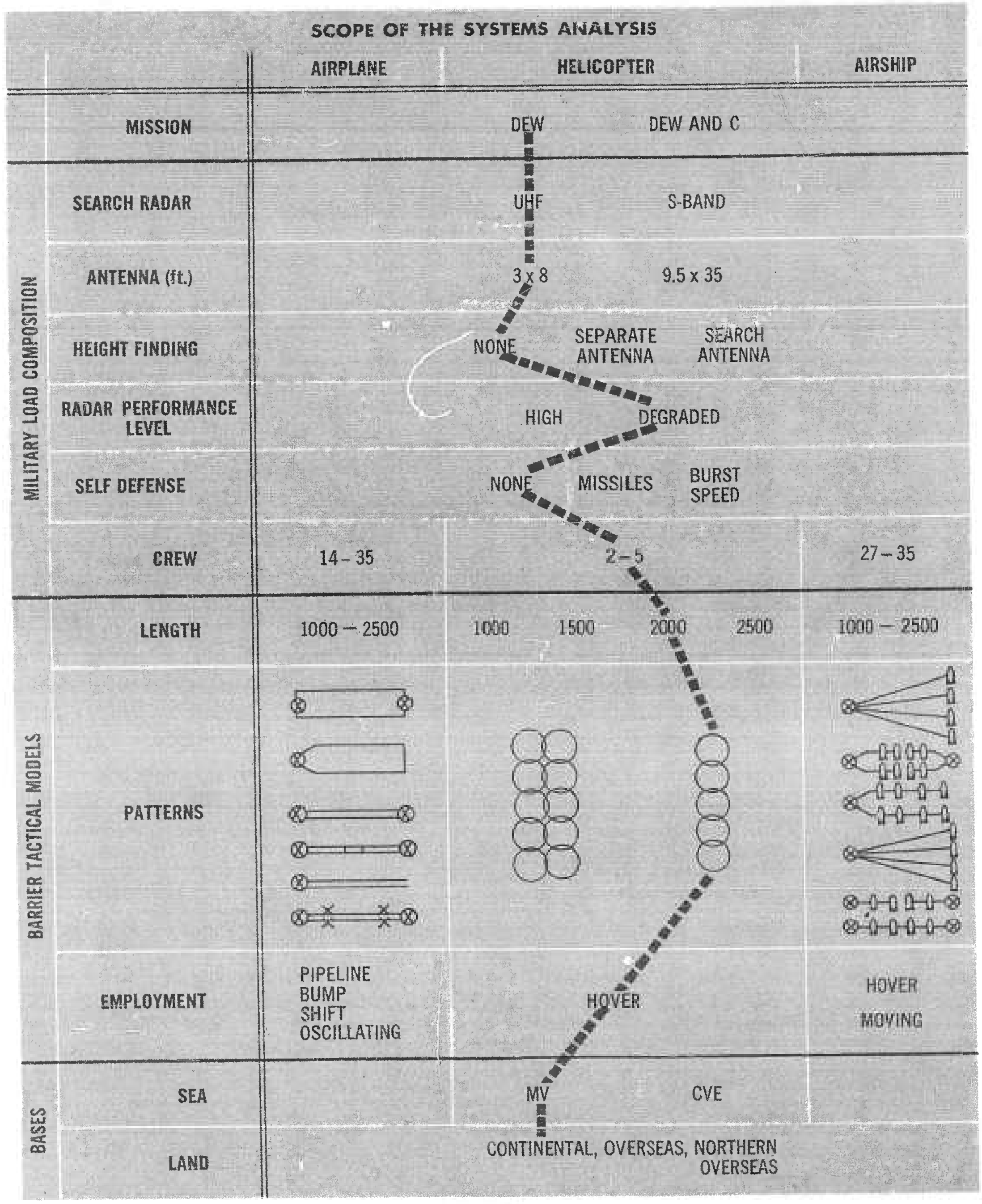

SCOPE OF THE SYSTEMS ANALYSIS
AIRPLANE
HELICOPTER
AIRSHIP
MILITARY LOAD COMPOSITION
MISSION
DEW
DEW AND C
SEARCH RADAR
UHF
S-BAND
ANTENNA (ft.)
3 x 8
9.5 x 35
HEIGHT FINDING
NONE
SEPARATE ANTENNA
SEARCH ANTENNA
RADAR PERFORMANCE LEVEL
HIGH
DEGRADED
SELF DEFENSE
NONE
MISSILES
BURST SPEED
CREW
14 – 35
2 – 5
27 – 35
BARRIER TACTICAL MODELS
LENGTH
1000 – 2500
1000
1500
2000
2500
1000 – 2500
PATTERNS
EMPLOYMENT
PIPELINE
BUMP
SHIFT
OSCILLATING
HOVER
HOVER
MOVING
BASES
SEA
MV
CVE
LAND
CONTINENTAL, OVERSEAS, NORTHERN OVERSEAS

FIGURE 5.1

RANGE OF PARAMETRIC ANALYSIS VARIABLES

VARIABLE	AIRPLANE	HELICOPTER	AIRSHIP
MISSION	DEW, DEW & C	DEW, DEW & C	DEW, DEW & C
CONFIGURATION	BOTTOM MOUNTED RADOME ROTADOME	TANDEM ROTOR	RIGID NON-RIGID
POWER PLANT	RECIPROCATING TURBO PROP	RECIPROCATING GEARED TURBINE	RECIPROCATING
MILITARY LOAD (lbs.)	5000 TO 40,000	3000 TO 8000	5000 TO 40,000
ANTENNA SIZE (ft.)	4 x 17.5 TO 9.5 x 35	3 x 8 TO 7.2 x 33	4 x 17.5 TO 9.5 x 35
NUMBER IN CREW	14 TO 34	2 TO 5	27 TO 35
CRUISE SPEED (kts.)	150 TO 400	100 (max.)	60
ALTITUDE (ft.)	2500 TO 50,000	2500 TO 35,000	2500 TO 20,000
TAKE-OFF WEIGHT (lbs.)	50,000 TO 300,000	7500 TO 80,000	—
WING LOADING (lbs./ft.^{2})	30 TO 50	—	—
ASPECT RATIO	12, 14	—	FINENESS RATIO 4.175
DISC LOADING (lb./ft.^{2})	—	1.5 TO 4.5	—
ROTOR TIP SPEED (ft./sec.)	—	550 TO 850	—
TIME ON STATION (hrs.)	—	—	24 TO 360
TRANSIT RADIUS (n. mi.)	—	—	0 TO 1500

FIGURE S.2

The cost to the U.S. includes the cost of the aircraft system and basing facilities. Throughout the study the design of the barriers is based upon attaining a minimum cumulative probability of detection in the barrier of 0.9. The best early warning system, therefore, is the one for which the cost to the U.S. for a level of detection of 0.9 is a minimum.

At the present time the Navy is planning to implement and operate an early warning system consisting of certain barriers in the Atlantic and Pacific. Changes in future requirements may dictate different locations for these barriers. In order to allow for such variations, a series of barrier lengths consistent with geographical limitations was analyzed. These are illustrated in Figure S.3.

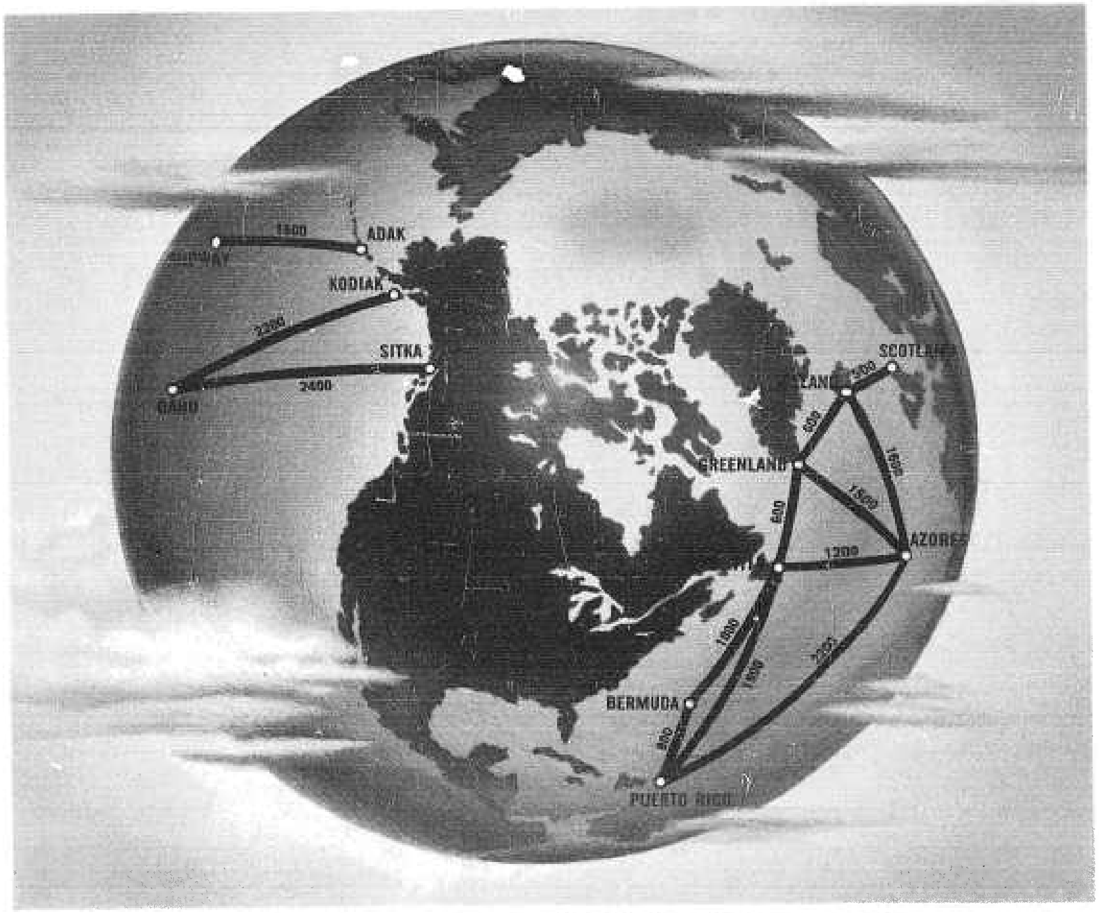


FIGURE S.3 – POSSIBLE OVERWATER EARLY WARNING BARRIERS

RESULTS

Characteristics of Optimum Aircraft

The characteristics of the optimum aircraft for DEW and DEW & C are given in Figure S.4. For example, the characteristics of the optimum DEW airplane, assuming that moving target indication (MTI) is achieved, are given in Column A; for DEW & C with and without MTI are shown in Columns B and C respectively.

In the following paragraphs certain of these aircraft are examined in environments other than those on which their design is based. Through a

process of elimination. optimums of each vehicle type are determined, and finally the optimum from among these three is selected.

Selection of Best Systems - MTI Available

In Figure S. 5 the annual system costs for a representative network consisting of two barriers are indicated for airplane, helicopter and airship systems designed for and used in DEW missions. These systems are designated respectively as A, D, and F, in Figure S. 4. Indicated in S. 5 are costs for airplane, helicopter and airship MTl optimums designed for DEW & C but used in DEW missions. These DEW & C systems are designated as B, E, and G in Figure S. 4.

CHARACTERISTICS OF OPTIMUM AIRCRAFT

	AIRPLANE			HELICOPTER		AIRSHIP		
	A	B	C	D	E	F	G	H
	DEW	DEW & C	DEW & C	DEW	DEW & C	DEW	DEW & C	DEW & C
	MTI	MTI	NON MTI	MTI	MTI	MTI	MTI	NON MTI
MILITARY LOAD (lbs.)	24,000	28,000	28,000	3890	7130	25,500	32,000	32,000
RADOME (ft.)	6.3x31.5	6.3x31.5	6.3x31.5	—	—	—	—	—
ANTENNA (ft.)	6x25	6x25	6x25	5x22.5	5x22.5	7.2x30	7.2x30	7.2x30
CREW	14	18	18	2	5	27	35	35
ALTITUDE (ft.) CRUISE OR HOVER	35,000	35,000	5000	20,000	20,000	10,000	10,000	5000
POWER PLANT	T-PROP	T-PROP	T-PROP	TURBINE	TURBINE	RECIP.	RECIP.	RECIP.
GROSS TAKE-OFF WT. (lbs.)	90,000	110,000	130,000	15,000	30,000	—	—	—
SPEED (kts.)	225	225	150	—	—	—	—	—
RANGE (n. mi.)	2940	3220	3440	—	—	—	—	—
ON STATION ENDURANCE HOURS				1.6	2.4	—	—	—
TIME TO CLIMB TO ALTITUDE HRS				0.3	0.3	—	—	—
TRANSIT RADIUS						1250	1250	1250
ON STATION ENDURANCE						168	168	168
VOLUME MILLIONS OF CUBIC FT.						2.94	3.25	2.40

FIGURE S.4

During the establishment of the sea wing barriers, the earliest requirement will be to provide information to the continental defense system. As this system expands, the additional requirement for a control capability may appear. These considerations should influence the selection of an optimum aircraft system. In addition, Navy commitments in various tasks throughout the world dictate a control capability in early warning units used in conjunction with fleet operations.

A comparison of the system costs for the airplane and airship shown in Figure S.5 indicates that the penalty for using the DEW & C airplane and airship in a DEW barrier is about 10 per cent. The choice of a single airplane or airship to carry out both missions simplifies problems of logistics, support, training and procurement. Based on these considerations the DEW & C configurations (Systems B and C) of the airplane and airship are selected as optimum for the case where MTI is available.

The characteristics and costs of the helicopters to carry out both functions differ widely, and severe penalties are incurred if the DEW & C heli-

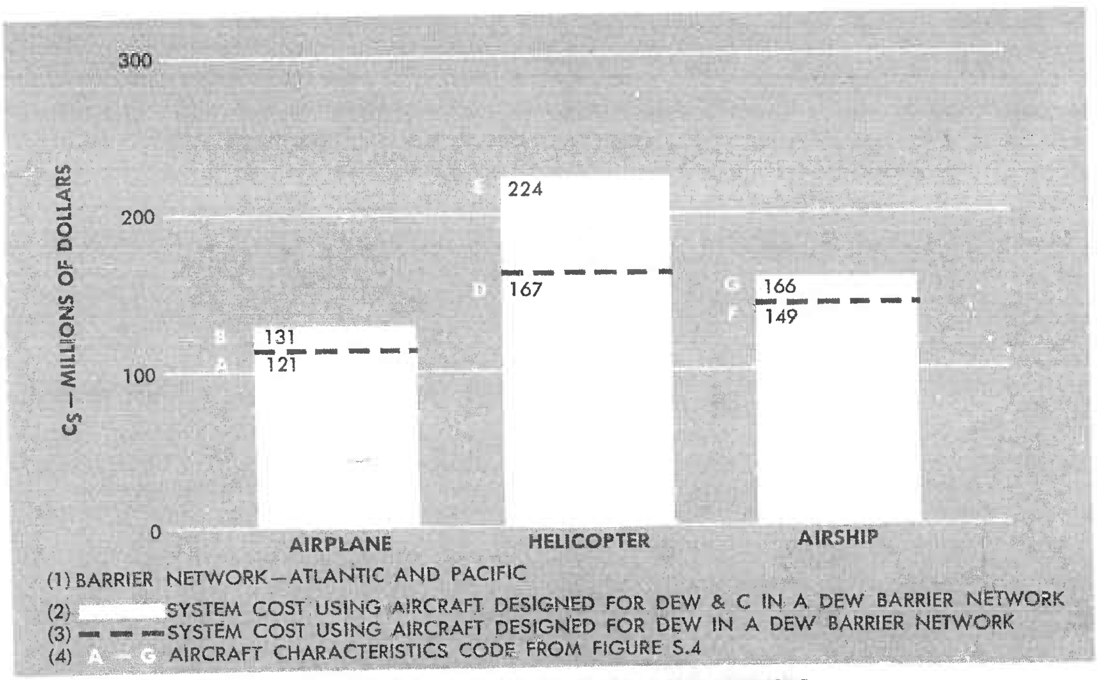


FIGURE S.5—SYSTEM COST FOR DEW BARRIERS

copter is selected and is used in a DEW barrier.

It therefore appears impractical to select a single helicopter to carry out both the DEW and the DEW & C missions.

The annual system costs for a network of DEW & C barriers are $279, $661 and $332 millions for the airplane, helicopter and airship respectively. It is apparent that the DEW & C helicopter is not competitive with the other systems.

Selection of Best Systems - MTI Not Available

The characteristics of the optimum airplane, if MTI is not available, are given in Column C of Figure S.4. If this airplane were flown under the conditions which determined its design, an annual network system cost of $132 million would result. This figure is to be compared with $131 millions for the MTI airplane design shown in Column B, Figure S.4. If on the other hand, the MTI airplane were selected, and MTI were not achieved, this airplane flown at the lower altitudes for the non-MTI case would involve an annual system cost of $290 millions. It is apparent, therefore, that the best airplane system is the one that is optimum for the non-MTI case, Column C, Figure S.4.

The helicopter that is optimum for the non-MTI case is incapable of operating at the higher altitudes to take advantage of MTI. The helicopter that is optimum for the MTI case pays very small penalties at the lower altitudes; therefore, the optimum helicopter is the one for the MTI situation.

The characteristics of the airship for the non-MTI case are shown in Column H of Figure S.4. The airship design for the MTI case pays somewhat larger penalties at the lower altitudes, however, in order to allow for growth potential the airship which operates at the higher altitudes for MTI is selected and has characteristics as indicated in Column G.

SELECTION OF THE OPTIMUM SYSTEM

Optimum aircraft have been described for each of the three vehicle types. The final step is the selection of an optimum system from among these three vehicles.

The airplane (Column C) designed for the non-MTI case and the helicopter (Column D) and airship (Column G) designed for the MTI case have

been selected as optimum. Figure S. 6 shows the annual cost of systems using these optimum aircraft in DEW barriers for both MTI and non-MTI situations. For the MTI case, if the radar performance level is achieved for which the airplane system is designed, the airplane system is less costly than the airship system by about 20 per cent. The areas under the solid lines in Figure S. 6 show the relative positions for this situation. If, however, the radar performance level for which the airplane system is designed is not achieved, the airplane and airship systems are competitive. The areas under the dotted lines in Figure S. 6 show this situation. It is apparent that strong attention should be paid to obtaining good radar performance since a reduction in early warning system costs can be achieved.

With regard to the helicopter it will be observed from Figure S. 6 that in no case is the helicopter a least costly system. Moreover in order to occupy a near competitive position it has no control capability. Only in the

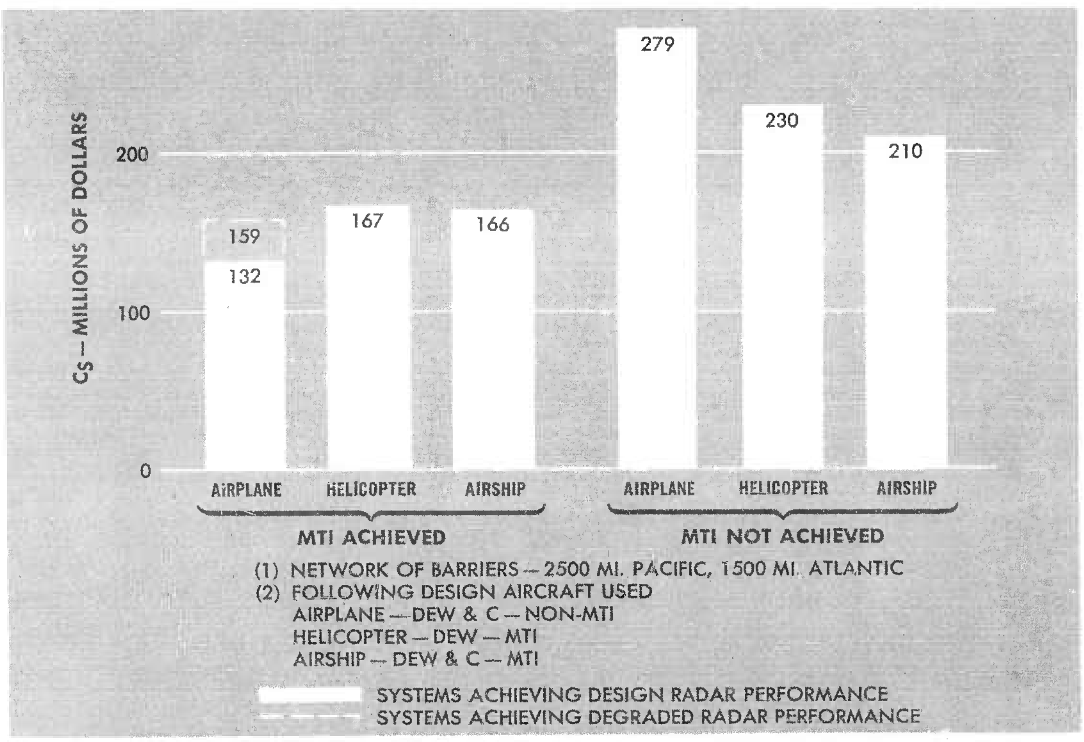


FIGURE S.6 — COMPARISON OF DEW SYSTEM COSTS USING SELECTED OPTIMUMS

unlikely situation that a control capability is not desired should consideration be given to the helicopter.

The selection of an optimum system is directly dependent on assessment of the probability of obtaining an adequate MTI system. Within the framework of this study, the selection involves the following:

1. If MTI is not achieved, the airship system is optimum. It is approximately 35 per cent less expensive than the airplane system.

2. If MTI is achieved, and if the lower radar performance level is obtained, there is little difference in the costs of the two systems. The airplane is slightly less costly than the airship but the difference is not of significant proportions.

3. If MTI is obtained as well as a higher level of radar performance, the airplane system is the optimum. It is some 20 per cent less costly than the airship.

The optimum airplane and airship for employment in a control barrier are identical to those selected for use in a DEW barrier. Figure S.7 summarizes the characteristics of the optimum aircraft.

Also shown in this figure are the system costs when these aircraft are employed in a DEW barrier. If the assessment is that effective MTI will not be achieved the selection is the airship. If the assessment is that MTI will be achieved, the selection is the airplane.

IMPORTANT FACTORS

Radar

The failure to develop an effective MTI will have significant effects on the cost of establishing an early warning barrier, and on the selection of the optimum aircraft system. Airplane system costs are more than doubled if MTI is not achieved and the costs of the other two aircraft systems are materially affected. It is apparent that important benefits can be gained from a vigorous program for development of an effective MTI.

Important gains can also be achieved by stressing maintenance and training programs to obtain the high level of radar performance.

THE OPTIMUM AIRCRAFT				
CHARACTERISTICS	AIRPLANE		AIRSHIP	
CONFIGURATION	DEW & C		DEW & C	
MILITARY LOAD (lbs.)	28,000		32,000	
RADOME (ft.)	6.3 x 31.5		—	
ANTENNA (ft.)	6 x 25		7.2 x 30	
CREW	18		35	
POWER PLANT	TURBOPROP		RECIPROCATING	
GROSS TAKE-OFF WEIGHT (lbs.)	130,000		—	
VOLUME	—		3.25	
ALTITUDE (ft.)	5000	35,000	5000	10,000
CRUISE SPEED	150	250	60	60
RANGE (n. mi.)	3440	3900	—	—
TRANSIT RADIUS	—	—	1250	1250
ON STATION ENDURANCE (hrs.)	—	—	147	168
	NON-MTI	MTI	NON-MTI	MTI
DEW SYSTEM COSTS (millions of dollars)	279	132	210	166

FIGURE S.7

Communications and Navigation

An examination of conventional and currently available airborne communications equipment indicated that these are inadequate to meet the communications performance level, rate, and reliability demanded by distant early warning and early warning control operations. Currently available techniques, in a form new to airborne use, can be adapted by development to meet the specific requirements of the airborne systems under study. Chapter III proposes a system to meet the above requirements.

Aircraft Utilization

The system costs can be reduced by increasing the utilization of the aircraft employed. The selection of the optimum system is sensitive to the utilization values that might be achieved.

Tactics

The tactics employed can change force requirements by a factor of two without altering the probability of detection of the barrier. The optimum aircraft for a network of barriers must use the appropriate tactics for each of the barrier lengths comprising the network in order that system cost be minimized.

Control Capability

The addition of a control capability to the airplane and airship does not significantly alter the characteristics or system costs. For the helicopter, addition of a control capability increases the cost by significant values. Without MTI the control capability is minimal.

CRITIQUE

In addition to the important factors discussed, certain other factors remain which are difficult to quantitatively evaluate because of lack of adequate data, or because of the limitations of the framework of the study. These items become important when two or more systems are competitive from the standpoint of the measure of effectiveness used in this study.

Vulnerability

Aircraft vulnerability may be an important factor during a hot war. The three types of aircraft are vulnerable to enemy attack in varying degrees. The airship is the most vulnerable of the three both because of its size and its low speed. The helicopter presents a somewhat more difficult target because of its smaller size and high maneuverability but its lack of speed is a deficiency. The airplane is the least vulnerable of the three vehicles because of its speed and altitude capabilities.

Mobility

Both the vulnerability and flexibility of the barrier are affected by aircraft mobility. First, the units have a flexibility within the barrier to replace the components of the barrier. Second, the barrier itself has mobility in the sense that it can change old locations or establish new ones.

In the first instance, the helicopter system can replace aborted units in the shortest time, the airplane next, while the airship requires the long-

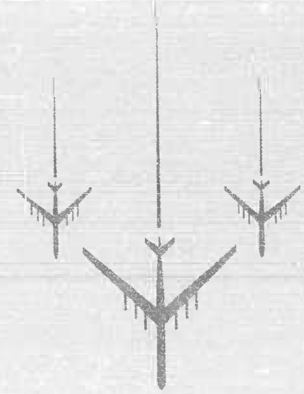
est time. For the second case, the mobility of the airplane is vastly superior and new barriers could be established in a few hours. The airship would require from four to five times as long as the airplane. The helicopter system appears to be not even competitive since the establishment of new barriers would be a matter of days.

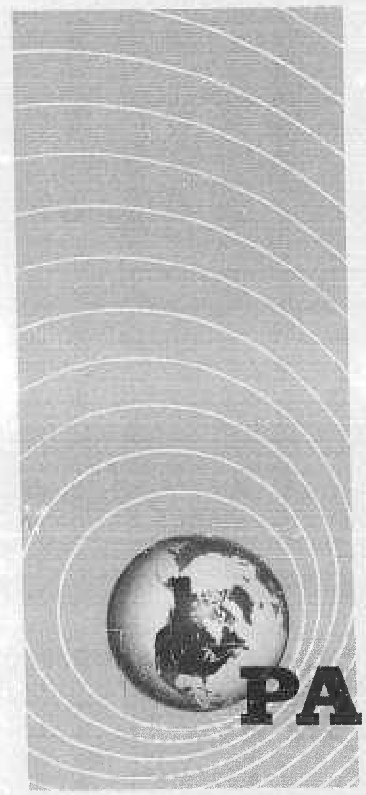
Electronic Countermeasures

Enemy employment of active ECM will degrade all the aircraft systems considered. This use of ECM will have no influence on the selection of an optimum within a type, or on the selection of an optimum system. It does have a significant influence on the effectiveness of the early warning line, particularly a barrier that is established to control intercepts. The use of active ECM is a type of warning in itself in the cold war situation.

Weather

The influence of certain aspects of weather have been examined; for example, head winds and icing for their effect on aircraft design, sea state for its effect on radar performance. The effects of surface weather conditions on handling of aircraft and the effects of extremes of weather have not been included.





PART I

- THE PROBLEM

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CHAPTER I

CHAPTER I

THE PROBLEM

Late in 1953 when it became apparent that some alteration of the inter-service agreements was about to be made, the Office of Naval Research requested the Military Operations Research Division to perform a study of airborne weapon systems for continental defense of the United States against possible attacks from the seaward approaches by enemy submarines and enemy aircraft during the period 1958-1962.

The task order listed objectives of the study as follows:

"(1) To comprehensively analyze the problem of integrating the airborne AEW and ASW efforts into the Continental Air Defense System.

"(2) To determine the characteristics of optimal airborne weapon systems which could become operational by 1960.

"(3) To develop a measure of effectiveness permitting selection of optimal airborne systems. This also will provide for comparisons of LTA and HTA weapon systems performing air defense missions."

Part of the contract arrangement was that the study should not begin until a Lockheed-sponsored analysis then in progress was completed. This company study had been undertaken originally by the Military Operations Research Division in order to quantitatively assess the value of airborne early warning and control of intercept for the 1955 time period, and to indicate methods of employment of airplanes configured for such functions. The results of the study were published 15 April 1954 as Lockheed Report 9740. The research carried on for this project provided much valuable background information and indicated areas of further investigation. Shortly after the task assignment was received from ONR it became clear that the Navy was to be given responsibilities for implementing and maintaining early warning of aircraft coming through the sea wing barriers and for providing and operating certain continental defense elements in the areas contiguous to the shoreline. As these responsibilities were designated, the objectives of the study were oriented to cover the job that had been assigned the Navy.

Another factor which assisted in the delineation of the scope of the study arose from early examination of the compatibility of simultaneous airborne early warning and anti-submarine search. The integration of AEW and ASW was first suggested by Project Hartwell in 1950, when it appeared that the huge costs of off-shore ASW search barriers might be shared for air defense if the vehicles could simultaneously search for both airborne and surface enemy vehicles.

While surveillance of the air, surface, and subsurface have common objectives, equipment and tactics differ markedly. An air surveillance system provides coverage of the surface, provided the target is large enough. However, in considering the employment of radar against snorkelling submarines certain basic limitations are apparent. Anti-radar coatings applied to snorkels drastically reduce the snorkel as a radar target. Accepting the fact that snorkelling submarine is not much of a radar target, a radar system for its detection operates at wavelengths much lower than those required for effective air search, and in addition the missions should be flown at different altitudes. Also, sonar subsurface surveillance with airborne units - possibly in conjunction with surface units - involves completely different equipments, and probably tactics, than for surveillance of the air. In view of such considerations, it appeared desirable to concentrate the efforts of the study on examination of the air surveillance problem, leaving the integration of AEW and ASW until knowledge of the former was acquired.

A third set of circumstances were considered in delineation of the problem. Airborne distant early warning systems may serve useful purposes in three military situations: the first has the characteristics of the present day cold war, the second is a transition period during which the first large hostile penetration is made which results in damage to the U.S., and third the period of ensuing enemy action, a hot war. The analysis of the cold war situation is of manageable scope. The hot war and possibly the transition to it, to be properly analyzed, requires a framework which includes the entire continental defense posture and the interaction of the enemy with it. To analyze effectively in this large framework, a knowledge must be acquired of its components. Therefore, it appeared desirable to intensively analyze the cold war situation, optimizing aircraft for use in early warning; and then to

study the effects on these optimizations of adding control capabilities that might be required during transition and hot war periods.

OBJECTIVES OF THE STUDY

This report is based upon an analysis of airborne distant early warning systems designed primarily to collect and transmit information of the approach of aircraft to the continental United States defense zones, in the time period 1960 to 1965. The selection of the aircraft to carry out a given military mission is a multi-faceted problem. The military planner must take into consideration such items as basing problems, geographic limitations, aerological factors, tactical and military situations, the state-of-the-art in component development, and many others. In addition, he must be aware of speed, altitude, power plant and weight limitations and all the corollary interactions of these factors.

In particular, in the design of a vehicle to accomplish early warning, a very careful analysis must be made of the radar, the communication and the navigation performance and limitations. The military planner must recognize the importance of proper selection of a radar and of attaining the radar performance level to which the system is designed.

The time period required to place an airborne system in operation is generally considered to be five to ten years, depending on the complexity of the system. Consequently, the airborne early warning system should be designed to cope with the types of aircraft that an enemy is expected to have operational in a future time period.

This analysis attempts to define, limit and relate the many thousands of combinations of important variables. It will quantitatively assess the relative values of the various airborne weapon systems by application of a measure of effectiveness, and will then select optimum systems in order to assist the military planner in his difficult decisions.

The specific objectives of the study are:

1. For both distant early warning and distant early warning and control,
   a. To determine the best airplane system;
   b. To determine the best helicopter system;
   c. To determine the best airship system.

2. To select the best airborne early warning system.

The report is divided into eight Chapters and four Appendices. Chapter I presents the objectives, assumptions, U.S. and enemy capabilities, and the general measure of effectiveness used in the analysis. Chapter II presents the analysis of airborne radar. Chapter III discusses the limitations imposed by navigation and communication equipment. Chapter IV outlines the tactical models used. Chapters V, VI and VII present the results of the airplane, helicopter, and airship system studies. Finally, Chapter VIII compares the relative merits of the various vehicles, and selects the optimum airborne early warning system.

During March, 1955, a preliminary review of the results of the study was made by members of CNO, BuAer, ONR, NADU (South Weymouth), NRL and Lincoln Laboratories. In the course of this review, three additional areas of interest were suggested for investigation and inclusion in this report. These are: (1) Radar performance level degraded by lack of MTI,* (2) In-flight refueling of early warning airplanes, and (3) barriers comprised of both airborne and surface search vehicles. These subjects are covered in Appendices A, B and C respectively. One other appendix is included, Appendix D, which treats the amount of control required in a distant early warning barrier.

ASSUMPTIONS AND BASIC CONSIDERATIONS

The primary objective of the early warning systems considered is to warn of the approach of aircraft. The manner in which this objective can be carried out is, of course, very influential in the design of the early warning system. Some of the many ways to obtain early warning are: by strategic warning, by intelligence, by the use of a ground observer corps in Europe, or by the establishment of barriers across the approach routes. This study investigates primarily only airborne weapon systems in barrier operations; and secondarily a combination aircraft-surface ship operation.

In delineating this problem three major assumptions are made.

(1) That the primary purpose of the barrier line is early warning of penetrating aircraft.

(2) That the 1960 threat is that designated in the Joint Intelligence Com-

*Moving Target Indication

mittee estimates. The primary threat assumed is the Type 37, a high performance jet bomber equivalent to our B-52. In addition, it is assumed that the enemy will have in significant numbers his Type 39, equivalent to our B-47, as well as TU-4's, Type 31 turboprop, and pilotless aircraft.

(3) That complete radar coverage from sea level to the maximum altitude expected for air breathing engines is achieved with a single airborne vehicle wehther it is airplane, helicopter, or airship.

The assumption that the primary purpose of the barrier line is early warning has one very important implication. The integrity of the line will be maintained in the sense that individual barrier aircraft will not pull out of the line to close unknown targets either for identification or kill purposes.

Figure I.1 illustrates assumption number three and indicates the radar coverage that might be obtained. The importance of this assumption will be discussed in greater detail in Chapter II of the report.

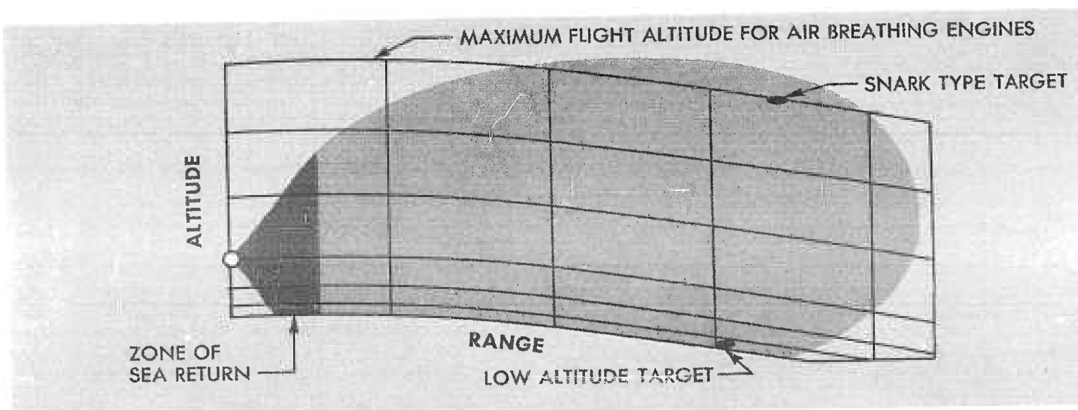


FIGURE I.1 — COVERAGE BY SINGLE VEHICLE

Primary Mission

As stated above the primary objective of the early warning system is to warn of the approach of aircraft. However, the strategic situation may require that the early warning barrier have two separate missions. In the cold war situation the mission would be to carry out the warning function, but in the transition phase a control capability may be useful in order that interceptors or missiles be controlled to counter, if necessary, aircraft which

penetrate the barrier. In this study the first of these missions is examined in the DEW or distant early warning barrier. The aircraft configured for this barrier are designed for warning only. The aircraft configured with a control capability will necessarily carry a larger military load and will be larger than those configured for warning only. An important part of this study is an examination of the changes in the system in order to incorporate the control function in the aircraft. No optimization of the amount of control necessary is made, but the early warning and control aircraft have selected amounts of control based upon considerations given in Appendix D.

Secondary Missions

Any early warning barrier can make several secondary contributions while carrying out its basic mission. For example, the aircraft in the warning barrier can be part of a weather system and, in addition, can be organized as part of an air sea rescue service. Although the aircraft designs are directly influenced by the fact that the primary target is aircraft, they could accomplish some surface surveillance. It has often been suggested that aircraft in the barrier doing early warning functions could also act as ASW aircraft. As has been indicated, such a configuration has not been examined. It must be re-emphasized that the design of these aircraft is not influenced by considerations of the secondary missions.

Geography

At the present time the Navy is planning to implement and operate certain barriers in the Atlantic and Pacific. Changing requirements in the future may dictate different locations for these barriers. In order to allow for such variations and still present a valid picture, a generalized set of barrier lengths is chosen that is consistent with geographical limitations.

Weather

Certain aspects of the influence of weather on the design and operation of early warning barriers are considered. The variation of average speed retardation with altitude for the over-ocean areas was determined and the values considered in design of the airplane. For the vehicles that hover, the average head winds were calculated for various areas of the world. An

examination is made of the influence on airship design if different head wind values are assumed.

Weather factors also affect the radar performance. Some of these effects are indirect, such as the influence of sea state on clutter, and some are direct as the effect of atmospheric anomalies on radiated energy. These factors are included within the limits of the amount of data available, and are of principal interest in consideration of the non-MTI, low altitude case.

Certain influences of weather are not considered because of lack of adequate data. These include the relative difficulty of ground handling of the various vehicles under adverse weather conditions; the problems involved in operating helicopters from sea platforms in heavy sea conditions; and the effect of heavy turbulence on radar detection probability.

ENEMY CAPABILITY IN 1960

The estimate of the enemy capability was derived after discussions with members of the various intelligence services, and review of several publications.[1,2] In general, no radical departures from these estimates are assumed. The two major target types considered are (1) aircraft and (2) missiles.

Aircraft Types

In terms of the target which they present to radar, the two distinctive aircraft types are propeller driven and turbojet. The radar reflecting area of the propeller types is roughly equivalent to that of the TU-4 is assumed to be approximately twenty square meters. In view of the lack of adequate data, no distinction has been made between the two turbojet types in reference to their radar reflecting area. It is assumed that both have equivalent radar reflecting areas of 7 square meters.

Missile Types

The status of the Soviet missile program is difficult to establish. JIC technical estimates assign the USSR a capability roughly equivalent to that

1. Joint Intelligence Committee Report 603116, Vol. I. *Estimate of Soviet Technical Capability*, 11 September 1953. (SECRET)
2. Air Technical Intelligence Command. *Study No. 102-AC-54/1-34*, 1 January 1954. (SECRET)

of the United States. Systems designed to provide early warning against inter-continental ballistic missiles and against aircraft are radically different in design, and there remains considerable doubt that an anti-ICBM warning system could be airborne. The airborne systems discussed here will provide some detection capability against winged missile types but will not be influenced by the consideration of the ICBM.

Of the winged missiles considered it is assumed that the Soviets may have a Snark or Navaho type. The radar reflecting area of such a missile is assumed to be roughly equivalent to that of a jet interceptor; that is, approximately one square meter. Optimum aircraft for warning against this type of target are not designed. However, the influence of such a target on the over-all system cost is examined. Another possible type is a submarine-launched missile. In terms of radar reflecting area, this missile is roughly equivalent to those already discussed and is treated in the same manner as the Snark type.

Numbers of Raiding Aircraft

As stated previously, the main function of the DEW line is to provide surveillance. Consequently, the system must be capable of detecting single aircraft or large raids. It is realized that raids with large numbers of aircraft would present much larger radar reflecting areas, but designs optimized on large raids would be relatively ineffective against single penetrations. Therefore, the aircraft systems are designed to provide warning against single targets.

Electronic Countermeasures

It is assumed that passive ECM equipment would be carried by the enemy to aid in exploiting possible gaps in the radar coverage. The enemy is assigned the capability of active ECM. The use of active ECM by the enemy will be dependent on the military situation.

UNITED STATES CAPABILITY IN 1960

Several elements comprising the U.S. capability enter this problem. The major elements in the problem are the aircraft, the radar, the navigation and communications equipment, the display and control components, and the supporting surface ships.

Airborne Vehicles

Three types of airborne vehicles are considered. These major types are the airplane, the helicopter and the airship. As discussed previously, two major configurations of each of these types are considered - for DEW and for DEW & C. The major difference between these two configurations is that the aircraft configured for control has additional electronic equipment and additional personnel.

Search and Detection Equipment

The primary search and detection equipment included is limited to the radar. Two major types of radar are examined. The first of these is the conventional S-band radar which is similar to the present day AN/APS-20B; the second radar is the UHF* radar. Two types of antenna systems are considered for use with the UHF, first the conventional reflector antennas and, second, a development known as the retarded surface wave antenna.[3] The S-band radar is assumed to have a conventional reflector antenna.

In addition to these search radars, certain configurations carry height finder radar. Here the main dependence is on two types. The first of these is similar to the AN/APS-45 which is mounted in the present-day WV-2. The second method of height finding is by the use of a lobing technique or a stacked beam antenna system. This would permit height finding without the addition of the special antenna and radome required with the AN/APS-45. These radars are discussed in more detail in Chapter II and in Lockheed Memorandum Report 7089.[4] For many of the factors which enter into the prediction of radar performance there are meager quantitative data. The results of this report are sensitive to the assumptions of radar performance. An effort is made to define certain limits within which radar performance falls. This is done by assuming two levels of operational performance. These two levels are based on extrapolations from operational test data, and are discussed in detail in Chapter II. In addition, the question of whether or not MTI is achieved has a far-reaching influence on system cost. It is the consensus of those in the radar field that MTI for UHF systems has a high probability of being achieved by 1960. Consequently, Chapters V, VI and

*Ultra High Frequency; approximately 70 cm wavelength

3. *A New Type Radar Search Antenna.* Lockheed Report 10223, 29 November 1954. (CONFIDENTIAL)

4. W. W. Lindsay, Jr. and G. A. Korn. *The Analysis of Airborne Radar.* Lockheed Memorandum Report 7089, Military Operations Research Division, Lockheed Aircraft Corporation. 1 July 1955. (SECRET)

VII are based on the assumption that MTI is achieved. Appendix A is based on the pessimistic premise that MTI will not be achieved.

ECM

Various items of both active and passive ECM equipment might be included in the military load of the vehicles. After taking into account the purpose of the aircraft and the military situation for which they are designed, it was decided to make no specific provision for ECM equipment. It is believed that the enemy would gain nothing by employing radar in the areas in which the DEW lines are established. Even if the enemy would employ radar, active jamming by the DEW plane would appear to be of small benefit. The need for passive ECM is lessened since the detection range of the radar carried is quite large. In addition, it is doubtful that it is technically feasible to employ the large radar and passive ECM simultaneously. For the above reasons, no ECM equipment is provided the DEW aircraft.

Navigation and Communications

In general, the navigation equipment considered is of the self-contained type. No primary dependence is placed upon external systems such as Loran or radio direction finders. Various methods of communication are examined, including the conventional methods such as UHF and HF, as well as using among other things teletype and digital data links. As insurance against all communications links being inadequate, the cost of maintaining picket ships for communications relays is investigated. In addition, a method is suggested that combines the navigation and communication functions using airborne microwave links.

Display and Control Equipment

The display equipment considered is of the conventional type and similar to that now carried in the airborne early warning aircraft. However, the control equipment is quite different from the consoles presently used. It is assumed that an airborne version of a computer similar to the General Electric AN/GPA-37 can be developed for the time period considered. This manually aided tracking computer is designed to handle 12 tracks simultaneously. The weight of equipment is approximately equal to that of one of today's control consoles. In the hands of a good CIC officer, using informa-

tion from a present-day console, two simultaneous intercepts can be conducted. It appears that considerable returns can be obtained if the present-day consoles can be replaced by some such airborne computer system.

In the helicopter system the necessity for minimizing weight is realized and therefore it is assumed that a video relay will be used to transmit the radar picture from the helicopter to the CIC on the station ship.

Surface Vessels

In the present planning of early warning barriers, two types of picket ships are being considered. These are the destroyer escort radar (DER) picket, and the converted Liberty Ship (YAGR), which carry air search radars and control equipment. In this study, where picket ships are considered, it is assumed that they are of the DER type and have characteristics similar to those outlined in OpNav Notice 09010.56 of 9 June 1954. These picket ships are considered for their use as communication relays and navigation check points. In addition, in Appendix C, they are considered as contributors to the effectiveness of the barrier radar search.

Two other types of ships are considered as floating helicopter bases. The first of these is a Liberty Ship which has been converted with a flight deck forward of the bridge structure in order to handle the helicopters. In addition to helicopter handling facilities, these ships have CIC facilities with equipment for receiving video information from the helicopters. The second type of ship considered as a floating base is the CVE.

Self-Defense Capability

Although no attempt is made here to determine the value of defending this aircraft, several methods of defense are analyzed. The first of these is to provide a short range air-to-air missile, similar to the present Sparrow type. In addition to the missiles themselves, certain auxiliary equipment is required, composed of such items as an AI radar, an airborne computer system, a height finder radar, and possibly ECM equipment. The use of missiles is analyzed for the airship, but this method of defense is not feasible for the helicopter system. The defense of the helicopter system could be achieved by armament carried on the basing ship. However, the cost of this defense method was not incorporated in the study. A second

defense weapon of the early warning airplanes is speed. This speed is used only for escape purposes in case of being attacked. An examination is made of the cost of adding burst speed to the early warning airplane.

Tactical Models

Since the requirements for the various aircraft types examined in this study generate such widely differing models, a generalized tactical model has not been selected. The models investigated involve various barrier lengths. barrier patterns, methods of employment, and base configurations. Different barriers are considered for the case of distant early warning and distant early warning and control. The principal distinction is that the distant early warning and control barriers have considerable depth in order to carry out the functions of detection, evaluation, decision and control of intercepts while the target is still within the radar coverage.

The number of tactical models for the helicopter system is small. The helicopter is stationed aboard this floating base and rises to altitude, acting as an elevated antenna. Here again, in order to provide the depth required for early warning and control, two lines of ships and helicopters are required.

Several variations of tactical models were considered for use in the airship case. After discussions with Goodyear Aircraft Corporation and Bureau of Aeronautics representatives it was decided that only the hover case for the blimp would be considered, since maintaining a moving line with airships would be extremely difficult. In the airship case, tactical model variations are examined for the distant early warning barriers. The distant early warning and control barriers are considered to be double lines and no special tactical models for the DEW & C case are required. The tactical models will be discussed in detail in Chapter IV.

SCOPE OF THE ANALYSIS

The objectives of distant early warning and distant early warning and control, the enemy and U.S. capabilities, and the tactical models, have been briefly outlined. As is apparent, many combinations of the various factors thus far considered are possible.

Certain other factors are strongly affected by the military situation, by

whether a cold war or a hot war is in progress. These factors are the amount of control capability required, the value of self defense, the physical vulnerability of the early warning aircraft, the value of mobility, and degradations of system performance by enemy ECM.

For a cold war situation, the first three factors do not appear important. Mobility, however, does affect the ability of the line to maintain integrity if aborts occur. This effect is analyzed in Chapter III. The effect of active ECM employed by the enemy has not been evaluated because of its widely varying aspects. It is believed, however, that active ECM will not have a significant effect on the basic design characteristics of the early warning aircraft; rather, it will degrade any system. If the enemy were trying to penetrate a barrier without being detected active ECM would be used only after they were certain they had been detected. The use of active ECM would degrade the control capability rather than the detection probability. This degradation that active ECM will provide is difficult to evaluate even when the total air defense posture is considered. Enemy passive ECM would be used to find and to exploit weak points of the barrier. This consideration has affected the design of the tactical models and aircraft spacings.

For a hot war, all of these factors are probably important. The first of these factors - the amount of control capability required - cannot be absolutely determined without a framework for the study which encompasses the entire air defense posture. A sub-optimization has been conducted on the necessary amount of control capability.

Vulnerability, self-defense, and certain aspects of mobility are connected with survival of the early warning aircraft if attacked by the enemy. It is the firm belief of the study group that a determined enemy can successfully destroy early warning aircraft in a barrier if he wants to. Therefore, only the equipment needed to remove the "sitting duck" situation is included, as previously indicated.

It is apparent that the three types of aircraft are inherently of different capabilities in surviving enemy attack because of their different sizes and speeds. The relative vulnerability of the three types has not been evaluated. Enemy ECM is treated in much the same manner for the hot war as for the cold war.

The major factors investigated are shown in Figure I.2. As an example, one possible combination might be a helicopter in a distant early warning function, carrying a UHF radar, based upon a merchant vessel, spaced for a degraded radar performance level in a 2000-mile barrier.

In addition to the major factors, many possible design parameters for the aircraft itself are considered. These basic parameters include range, speed, military load, power plant, flight altitude, and many others. The design parameters which are investigated, as well as the manner in which they are used, are discussed in Chapters V, VI and VII for the airplane, helicopter and airship respectively.

Measure of Effectiveness

In order to be able to determine which of the many thousands of possible aircraft designs is best, a common yardstick, or measure of effectiveness, must be applied to each one.

The measure of effectiveness used in this study is straightforward and simple. The prime mission of these barriers is to provide a certain level of detection. This level of detection is achievable by many methods, but each method requires a certain amount of the military budget. The military planner must generally operate on a limited budget, and if he is required to establish an early warning barrier, a fundamental consideration is the cost necessary to provide him with a certain detection level. Thus, a simple statement of the general measure of effectiveness is:

> The total cost to the U.S. is the sum of the cost of the aircraft system, including the cost of basing necessary to attain a given level of detection.

Throughout this study the design of the barriers is based upon attaining a minimum cumulative probability of detection in the barrier of 0.90. The best early warning system is the one that provides a given level of detection at a minimum cost to the U.S. This measure of effectiveness obviously does not take into account the value of early warning to the defense. This problem must be examined in the over-all framework of continental defense to determine the effects.

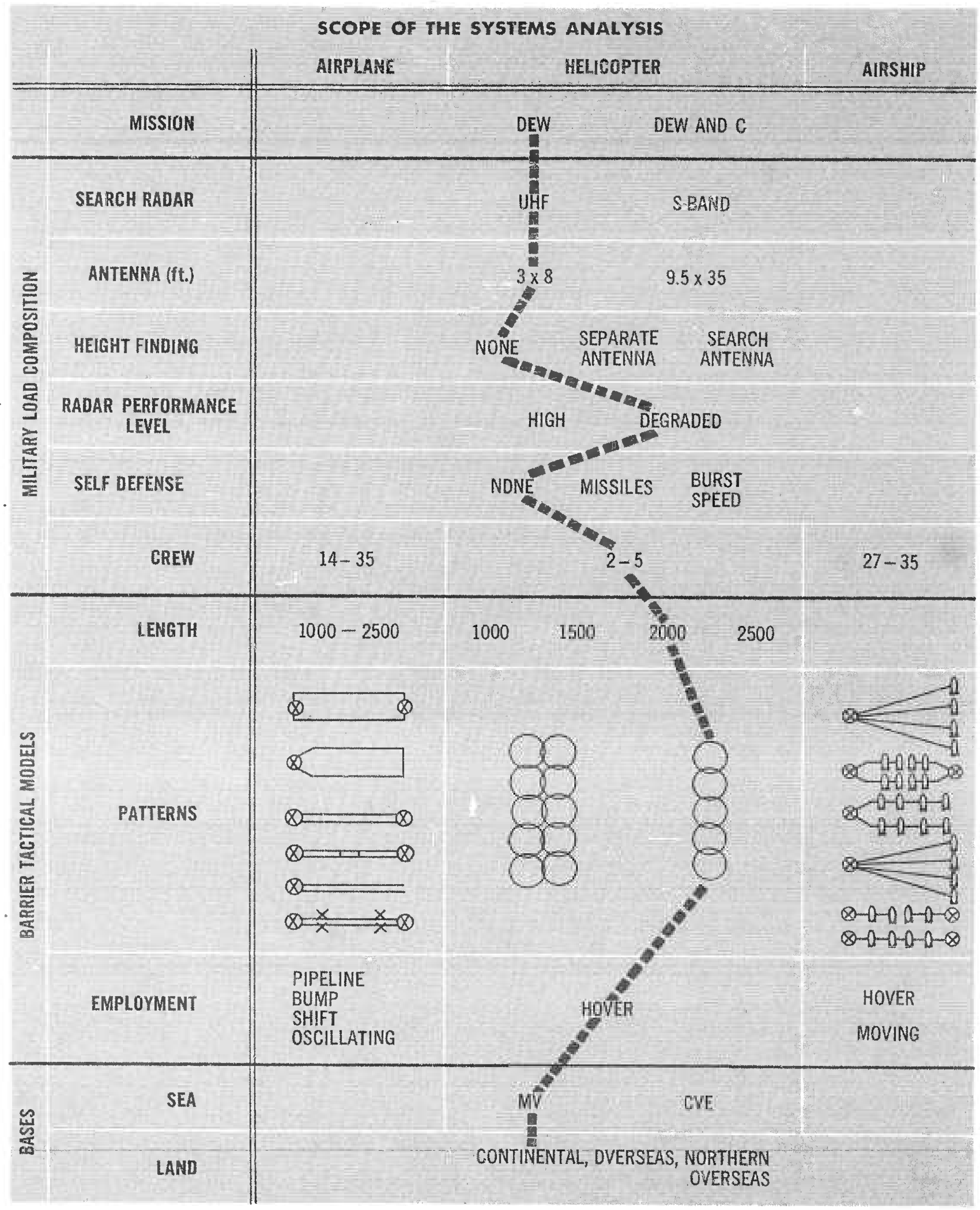

SCOPE OF THE SYSTEMS ANALYSIS
AIRPLANE
HELICOPTER
AIRSHIP
MISSION
DEW
DEW AND C
MILITARY LOAD COMPOSITION
SEARCH RADAR
UHF
S-BAND
ANTENNA (ft.)
3 x 8
9.5 x 35
HEIGHT FINDING
NONE
SEPARATE ANTENNA
SEARCH ANTENNA
RADAR PERFORMANCE LEVEL
HIGH
DEGRADED
SELF DEFENSE
NONE
MISSILES
BURST SPEED
CREW
14 – 35
2 – 5
27 – 35
BARRIER TACTICAL MODELS
LENGTH
1000 — 2500
1000
1500
2000
2500
PATTERNS
EMPLOYMENT
PIPELINE
BUMP
SHIFT
OSCILLATING
HOVER
HOVER
MOVING
BASES
SEA
MV
CVE
LAND
CONTINENTAL, OVERSEAS, NORTHERN OVERSEAS

FIGURE 1.2

Since a wide diversity of tactical models, barrier lengths and aircraft types is examined, the specific measures of effectiveness are discussed in more detail in the description of the various aircraft systems.

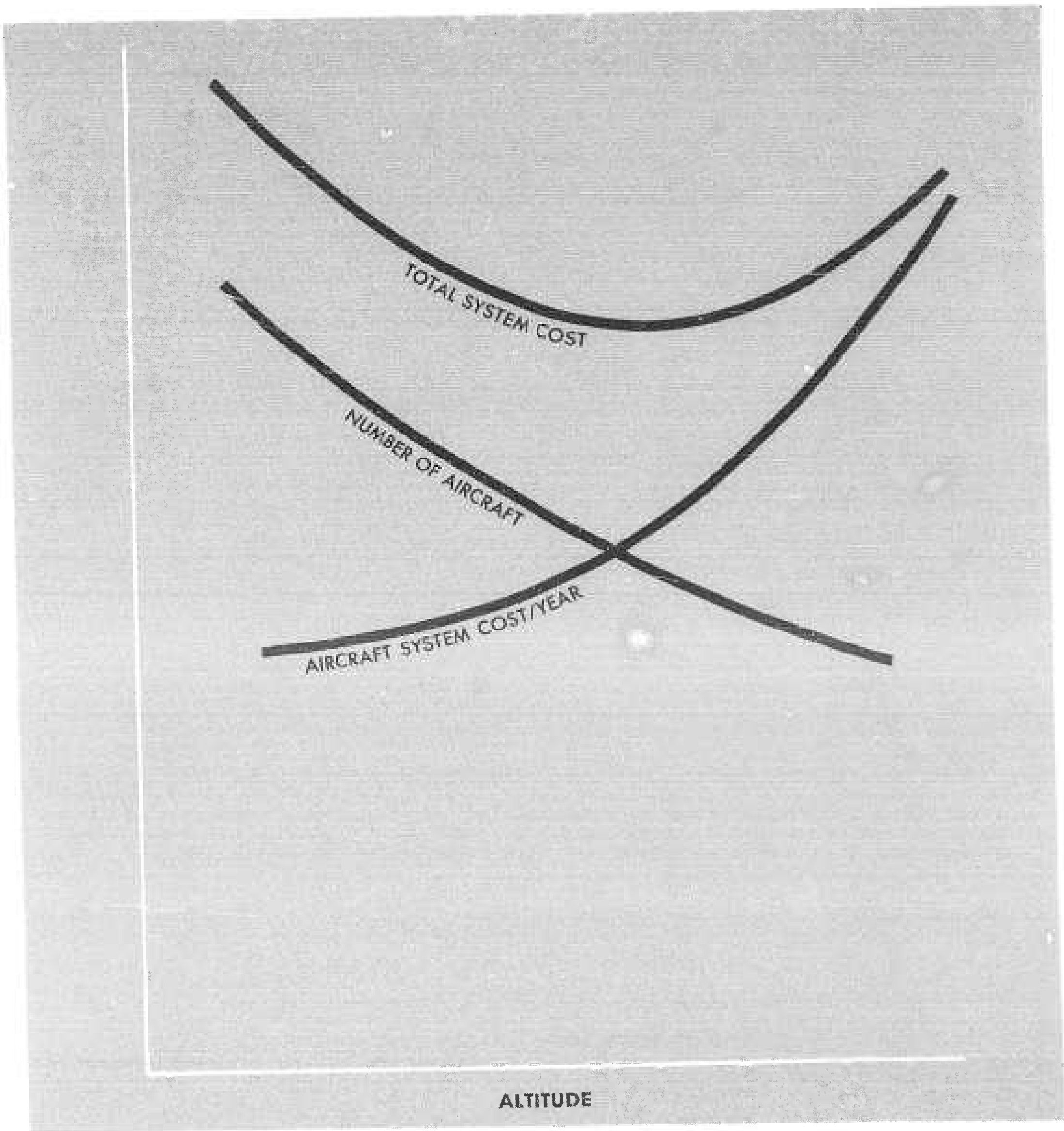
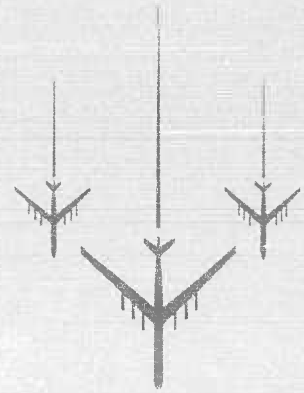


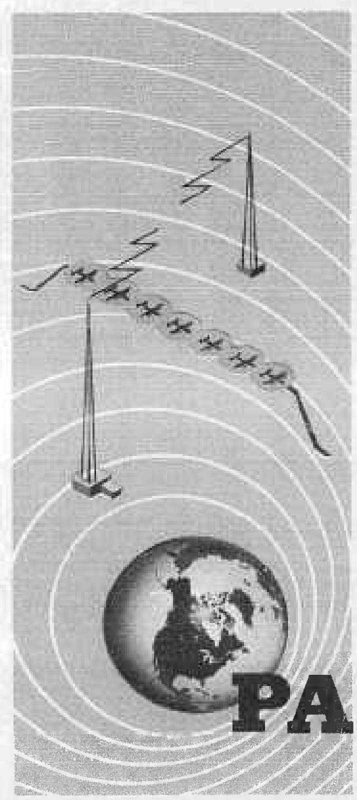
FIGURE I.3 — SELECTION OF OPTIMUM DEW AIRPLANE SYSTEM

If one were to select an aircraft to accomplish early warning, on the basis of the cost of that aircraft alone, very serious errors could be made. Figure I. 3 is a typical curve showing the general way in which the measure of effectiveness is applied to determine an optimum system. Altitude is the abscissa, since an increase in altitude increases aircraft spacing, and thus affects both the number of aircraft in the system and the cost per aircraft per year.

This figure shows that as the aircraft ceiling increases the cost per aircraft increases. The number of aircraft required to maintain the barrier decreases as altitude increases. The product of these two values then minimizes at a certain altitude. While increased altitude decreases the number of aircraft required, the cost per aircraft increases rapidly and more than counters the effect of saving in force requirements.

The final application of the measure of effectiveness permits one to select the optimum aircraft system from among the three aircraft types considered.





PART II

- AIRBORNE RADAR
- COMMUNICATION AND NAVIGATION
- TACTICAL MODELS

INDEX TO PART II

CHAPTER II

CHAPTER II

THE ANALYSIS OF AIRBORNE RADAR

INTRODUCTION

The proposed concept of airborne distant early warning and control barriers stands or falls with the performance of airborne radar equipment. Specifically, radar performance will determine the spacing between barrier aircraft and, consequently, the number of aircraft required to establish radar barriers having given detection and control capabilities. Radar performance, and therefore radar design, are quantitatively related to barrier costs and hence to the over-all measure of effectiveness developed in the preceding Chapter.

RADAR SYSTEMS FOR THE SEARCH FUNCTION

The following section will discuss the more important factors relating to the search function, for example, the effects of wavelength as related to sea clutter, enhancement of detection range, antenna size, system stability, MTI, and target scintillation. Implicit in these considerations is an examination of the equipments that the state-of-the-art can be expected to provide in the time period under examination. For a given wavelength and required azimuthal and elevation beamwidth, the antenna aperture and gain are determinable. Using the best available test data and taking into account target size and operational degradation, the performance of a given system in the form of blip/scan ratios has been determined. These data are then combined with operator factor using current search theory to calculate lateral range curves. Finally, the spacing of barrier aircraft is determined from these lateral range curves.

A later discussion will consider the problems associated with the addition of weapon control functions, such as height finding and elevation resolution.

Wavelength

A choice of wavelength for the search function should be based on a thorough assessment of performance determining factors and mission requirements. For reasons which are discussed later, longer wavelengths appear to be more promising for the search only case.

Selection of wavelength for determination of target altitude and control of intercept should take into account the performance determining factors, mission requirements and AI radar capabilities, such as lock-on range, and elevation and azimuth coverage.

Two different wavelengths appear desirable for combined search and control function radar systems. The selection of two appropriate wavelengths would make it possible to approach uncompromised performance for each function. A longer wavelength radar is required for search in order to provide reliable detection range and to reduce the effects of sea and cloud clutter, and a shorter wavelength radar for control of intercept and to increase target resolution and height finding accuracy. Additional features of dual wavelength radar systems are the lower susceptibility to jamming by opposing forces and increased reliability due to having two systems with overlapping search function capabilities.

The problem of sea clutter for a wavelength in the vicinity of 10.7 centimeters, particularly when flying at high altitude, is so severe that use of a longer wavelength in the region of 25 to 150 centimeters is essential in order to reduce the clutter spectrum and target scintillation, and to provide improved system stability. These improved characteristics make it possible to develop effective clutter suppression and automatic alarm circuits which are expected to significantly increase the probabilities of detection.

In the course of this study it became apparent that both equipment and data are available for examination of two wavelengths: S-band - 10.7 centimeters and UHF - 72 centimeters. The former is used in aircraft currently being procured and the latter is under intensive development by the Lincoln Laboratory.

Sea return has a pronounced effect on blip/scan ratio, particularly at S-band. Recent measurements have shown the sea clutter spectrum at S-band to be so broad that it appears hopeless to obtain a worthwhile improvement

by MTI or other techniques known today. For this reason, alone, it appears essential to use longer wavelengths. Even with longer wavelengths and the resulting narrower sea clutter spectrum there is still a sea clutter problem; however, with MTI the effects of sea clutter can be reduced sufficiently so that search and control operations will be possible even at high sea states.

The reflection coefficient of the sea surface is important, particularly for longer wavelength radars which benefit by the extension of detection range it provides. The effects of surface roughness have not been formulated in a quantitative manner, but recent operational tests indicate that at longer wavelengths the benefits of specular reflection are obtained even in high sea states. In actual operations the value of reflection coefficient obtained will vary with time for any given surface roughness and will also be a function of wavelength and flight altitude, or angle of incidence of the electro-magnetic energy in the radar beam. The operational data for UHF wavelengths indicate that sea reflection does not actually double the range, but appears on the average to provide a 40 per cent increase in range. Except for dead-calm seas, the enhancement of range is negligible for S-band wavelengths.

At S-band the lobe pattern of energy re-radiated from the target is made up of a fine structure of maxima and minima. This in turn is responsible for an undesirable scintillation due to small aspect changes inherent in normal flight of the target. In contrast, longer wavelengths such as UHF provide a coarser lobe structure and hence less scintillation of the reflected energy in normal flight.

Radar Design Parameters

Figure II.1 lists the design parameters of the search-radars for the two wavelengths discussed in preceding paragraphs. In addition, in the analysis, a number of combination search and height finding radars and dual-frequency radars with similar design parameters are considered.

The peak power, receiver noise figure, pulse length, and pulse repetition frequency are essentially fixed by the state-of-the-art. The only radar design parameter remaining to be chosen is antenna gain which is determined by the effective antenna aperture.

SEARCH RADAR SYSTEM PARAMETERS

	S-BAND	UHF
FREQUENCY (Mcps)	2800	416
WAVELENGTH (cm)	10.7	72
PEAK POWER (Mw)	2.0	2.0
PULSE WIDTH (in micro sec.)	2.0	6.0
REPETITION FREQUENCY (sec. $^{-1}$)	300	300
RECEIVER NOISE FIGURE (db)	9	6
SCANNING RATE (min. $^{-1}$)	6	6

FIGURE II.1

Antennas

The physical size and resulting gain of the antenna has the greatest effect on radar system performance. This is apparent from the fundamental radar range equation, in which range varies as the square root of antenna gain, whereas range varies as the fourth root of transmitter power. This relation shows the importance of large antennas, particularly for airborne systems. The size of search and control radar antennas for short wavelengths, such as 10.7 centimeters, should not exceed 25 feet in the azimuth plane. Otherwise the radar beam becomes so narrow that it cannot be adequately stabilized on an airplane platform, and the number of pulses per beamwidth on target with a suitable scan rate and pulse repetition frequency becomes too small to provide the desired information rate and range capability. For these reasons, antenna sizes considered in the final selection of 10.7 centimeter radar systems have been limited to dimensions which give azimuthal beamwidths greater than one degree.

At longer wavelengths, such as 72 centimeters, this restriction does not apply until the azimuthal dimension of the antenna approaches 165 feet. Antennas of this size may not be practical because of deflections of the airframe in flight which may cause phasing errors in reflectors and/or primary feeds, and in the case of helicopters and airplanes for other very obvious reasons.

It is apparent that airships can accommodate larger antenna structures than airplanes or helicopters with negligible weight and drag penalties. This feature can be exploited to provide greater spacings between barrier airships if not limited by the horizon. Alternatively the airship can be designed with a larger antenna to compensate for expected losses of radar component performance, such as transmitter power, receiver noise or a lower level of maintenance.

The vertical dimension of the antenna is also critical, particularly at 10.7 centimeters, if adequate altitude coverage of high-flying aircraft targets is to be obtained at shorter ranges. This means that a vertical beamwidth of 15 to 20 degrees is about the minimum that can be tolerated. The solution to this problem at 10.7 centimeters is either to shape the reflector to provide an approximate cosecant-square pattern, or to use a multiple-feed stacked-beam antenna system. The latter, although more complicated and possibly more difficult to maintain, has certain advantages at 10.7 centimeters, viz., (1) improved signal-to-noise characteristics, and hence greater range capability; (2) sea clutter will normally only affect the lower beam; and (3) height finding of a crude nature can be obtained by noting in which beam the target appears; more accurate height information can be determined by adding suitable computing components to a stacked-beam search system.

With 72-centimeter radars the vertical aperture should not exceed 10.5 feet. This provides a beamwidth of 15 degrees in elevation. Apertures with less than 4 feet vertical dimension which give beamwidths of more than 40 degrees, are considered too wasteful of power to be considered, except under special circumstances. These circumstances might be the deck-to-fuselage clearance required by certain special types of aircraft, or the use of less conventional antenna designs, such as surface or retarded wave types, such as are now under development at Lockheed. See Reference 3.

Most of the antenna sizes listed in Figure II.2 do not provide an ideal aspect ratio. Antennas with aspect ratios greater than 3:1 become increasingly more difficult to illuminate efficiently. In order to obtain a desired elevation coverage and azimuthal beamwidth, or to conform with the aerodynamic shape requirements of radomes, these departures from preferred antenna design are necessary. For the search radar systems under consideration, the azimuthal

beamwidth of the antenna essentially determines the azimuthal resolution. Narrow beamwidths or high resolution are beneficial in discriminating between targets at the same range and reduce the clutter area illuminated by the beam. On the other hand, wider beams may make it possible to distinguish target blips from noise blips more readily.

ANTENNA DIMENSIONS AND CHARACTERISTICS

	WAVELENGTH					
	10.7 cm BEAMWIDTH			72 cm BEAMWIDTH		
ANTENNA SIZE—ft.	ELEVATION DEGREES	AZIMUTH DEGREES	GAIN db	ELEVATION DEGREES	AZIMUTH DEGREES	GAIN db
3 x 8	7.7	3.2	30.1	65	22	13.7
3.5 x 9.2	6.6	2.8	31.4	51	18.1	14.8
3.5 x 14	6.6	1.73	33.1	51	12.5	16.7
4 x 17.5	5.8	1.46	34.8	43	9.9	18.4
6 x 25	3.85	1.03	38.1	27	7.0	21.5
7.2 x 30				22	5.8	23.1
9.5 x 35				17	5.0	24.6
10 x 50				15.8	3.5	26.8

FIGURE II.2

Blip/Scan Ratios

The blip/scan ratio is descriptive of the ability of the radar system to provide a useable return signal from the target. Before developing these blip/scan ratios from the factors previously discussed, four more items must be considered. One of these is the flight altitudes of the search aircraft and target aircraft. The second is the effective radar reflecting area of the

target. Third is the degradation of performance suffered by equipment when in operational use, and fourth is the effect of refractive anomalies and ducts.

A basic assumption is that the flight altitude of airborne search systems should be that altitude which gives a radar horizon distance equal to the mean value of the blip-painting range of the radar on specified aircraft targets flying at low altitude. This radar flight altitude will provide approximately the same detection range on similar size targets flying at higher altitudes up to 80,000 feet, except for limitations imposed by the vertical coverage of the radar system. The minimum flight altitude of the target aircraft for this study is assumed to be 500 feet.

In order to realize the maximum capabilities of longer wavelength systems, it would be essential to fly the largest antenna compatible with aircraft altitude and range performance. However, certain compromises between radar and aircraft performance, such as antenna size versus altitude and range and aircraft speed versus best MTI operation, may be necessary in order to achieve an optimum system that will meet the mission requirements with minimum cost.

The effective radar reflecting area of the primary target aircraft (jet bomber) is expected to vary between $2m^2$ and $12m^2$ depending on the angle of view, altitude and direction of flight with respect to the airborne radar. The value of $7m^2$ was finally selected as a reasonable average value for random penetrations of the search zone. The effect of choosing a lower value of $2m^2$ is either (1) to increase the force requirements and costs of the whole system for an equivalent probability of detection, or (2) to make the probability of detection vary along the penetration line if the spacing of aircraft is not decreased. Due to the increase in effective radar reflecting area (more favorable aspect angle) as the target aircraft penetrates the detection zone, this result may not be too serious for the search only case. If control of intercept is required, the problem is more serious, since loss of detection range means a loss of alerting time, and this delays all of the subsequent system functions, such as determination of range, bearing, track, altitude, identification and control.

Loss of performance due to maintenance degradation affects the operational performance of airborne radar systems. Surveys of various types of

radar systems during World War II have shown the mean performance to be 8 to 10 decibels below the rated value for the radar. Although no recent large scale surveys have been made, it is apparent from isolated reports[5] that maintenance losses have not been greatly reduced. Since a loss of performance of 12 decibels is equivalent to reducing the range to one-half, it is apparent how important it is to establish high maintenance standards and to provide continuous in-flight monitoring of radar system performance.

The reliability of performance is equally important since the radar is a vital component of the airborne system. By giving proper emphasis in design to the various factors which influence the operational reliability, such as, selection of quality components, proper derating, and adequate cooling, etc., it is believed that radar systems can be developed which will provide round-the-clock reliability with high performance if adequately maintained.

For the purposes of this study two levels of performance have been selected to bracket the expected operational performance. Level 1 represents a radar system capability provided by a high standard of maintenance and equipment adjustment, i.e., well trained maintenance personnel and alert, well-motivated operators. Level 2 represents a radar system capability degraded by lower maintenance standards and incorrect equipment adjustment. Under these conditions, even a good operator's performance is reduced. This loss of performance can be attributed to several factors, such as loss of transmitter power, poor spectrum and increase of receiver noise level.

It was assumed that radar systems in operational use would not be well enough maintained to equal the performance of laboratory systems which provided the test data for extrapolation of blip/scan curves. For purposes of analysis the level 2 degradation of radar system capability has been assumed to be equivalent to a two-way loss of 4 to 6 decibels[6]. This loss value has been applied to all search radars irrespective of their operating wavelength or complexity.

Anomalous propagation (ducts and nonstandard refractive conditions) at times exert a profound effect on radar coverage. The effects of anomalous

5. *Maximum Ranging Performance of Radars as Experienced by Commander Operational Development Force.* Special Report, 10 June 1954. (CONFIDENTIAL)

6. *Contiguous Radar Coverage in the U.S. Air Defense System.* Rand Report No. RM-1077, 1 May 1953. (SECRET)

propagation conditions are being studied, but the available data and methods of applying them to airborne radar predictions are only qualitative in nature. As a result of experience it is known that refractive anomalies and ducts frequently occur from sea level to altitudes of several thousand feet with sufficient density to cause severe bending and trapping of electro-magnetic energy. This implies that the effectiveness of an airborne radar barrier will vary as a function of weather due to bending or trapping of energy in certain altitude layers. Two possible methods of reducing the affect of refractive anomalies have been considered. These are: 1) increased effective radiated power, and 2) higher flight altitudes than have been previously considered for DEW operations in order to extend the useful range beyond which the radar beam becomes seriously affected by refraction. The first method does not appear attractive due to limitations imposed by 1) power available from transmitter tubes in the foreseeable future; 2) the physical size and resulting gain of flyable antennas; 3) the losses in radome structures; and 4) the trapping effect of refractive anomalies may exceed any practical increase in effective radiated power. In other words it does not appear that the solution to the problem created by refractive anomalies of the atmosphere can be solved by adding bigger and better black boxes to the airborne system. The second method, that of flying the airborne system considerably above the altitude at which refractive anomalies occur, is a tactical solution to the problem that appears promising and feasible providing the airborne system is suitably designed for such operational altitudes and the effects of sea clutter can be efficiently reduced by an effective MTI system. The effect of refractive anomalies on spacing S and detection probabilities of barrier operations if effective MTI is not achieved are discussed in Appendix A.

The effect of nonstandard refraction will also introduce errors in height finding which may be serious. Techniques which compare the height of the aircraft target with respect to the sea return may be useful with certain types of ducting. Possible gaps in radar coverage caused by trapping, make this approach to the height finding problem distinctly limited in scope.

Blip/scan curves for the various radars with characteristics specified in Figure II.1 were computed by extrapolation of 10 centimeter and 70 centi-

meter operational data given in Reference 7 for several values of flight altitude, target reflecting area, antenna size, and operational degradation. Figure II.3 shows typical blip/scan curves used in the evaluation study and illustrates the effects of parameter changes and search aircraft flight altitudes of 20,000, 27,500, and 35,000 feet on the blip/scan ratio. The blip/scan curves shown in Figure II.3 include an estimated effect of sea return, assuming the use of double-delay clutter lock MTI. See References 7 and 8. A further assumption is that the sea clutter radius varies as the square root of the flight altitude.

Search Theory

Each airborne weapon system contains a radar whose end product is information displayed on a radar scope and an operator who observes and interprets this information. Detection of target aircraft is essential for proper functioning of the entire system. Detection is followed by other system functions, such as determination of range, bearing, track, altitude, identification, and control of intercept. In all cases it is desirable to detect target aircraft at maximum range.

Up to this point the discussion has covered that part of the radar system which yields information on a radar scope. The purpose of this section is to combine these data with the performance of the operators in a quantitative relationship describing their over-all performance in providing a probability of detecting targets penetrating the barrier.

The essential element of an airborne radar barrier is a radar aircraft flying along the barrier line with ground speed v_o (Figure II.4; $v_o = 0$ for stationary or orbiting aircraft). Discounting the possibility of large gaps in the radar barrier and of extraordinary wind conditions, enemy bombers will attempt to penetrate the barrier at right angles to the barrier line. The track of such a bomber relative to the radar aircraft is indicated in Figure II.4; each such relative track may be labelled by its lateral range X, defined as the smallest distance between the bomber in question and the radar aircraft.

7. Lincoln Laboratory. *Comparative Performance of 10-cm and 70-cm Radar Over the Sea.* Technical Report No. 56, 25 August 1954. (SECRET)
8. Rand Corporation. *Some Pulsed Doppler MTI and AMTI Techniques.* Report No. R-274, 1 March 1954. (SECRET)

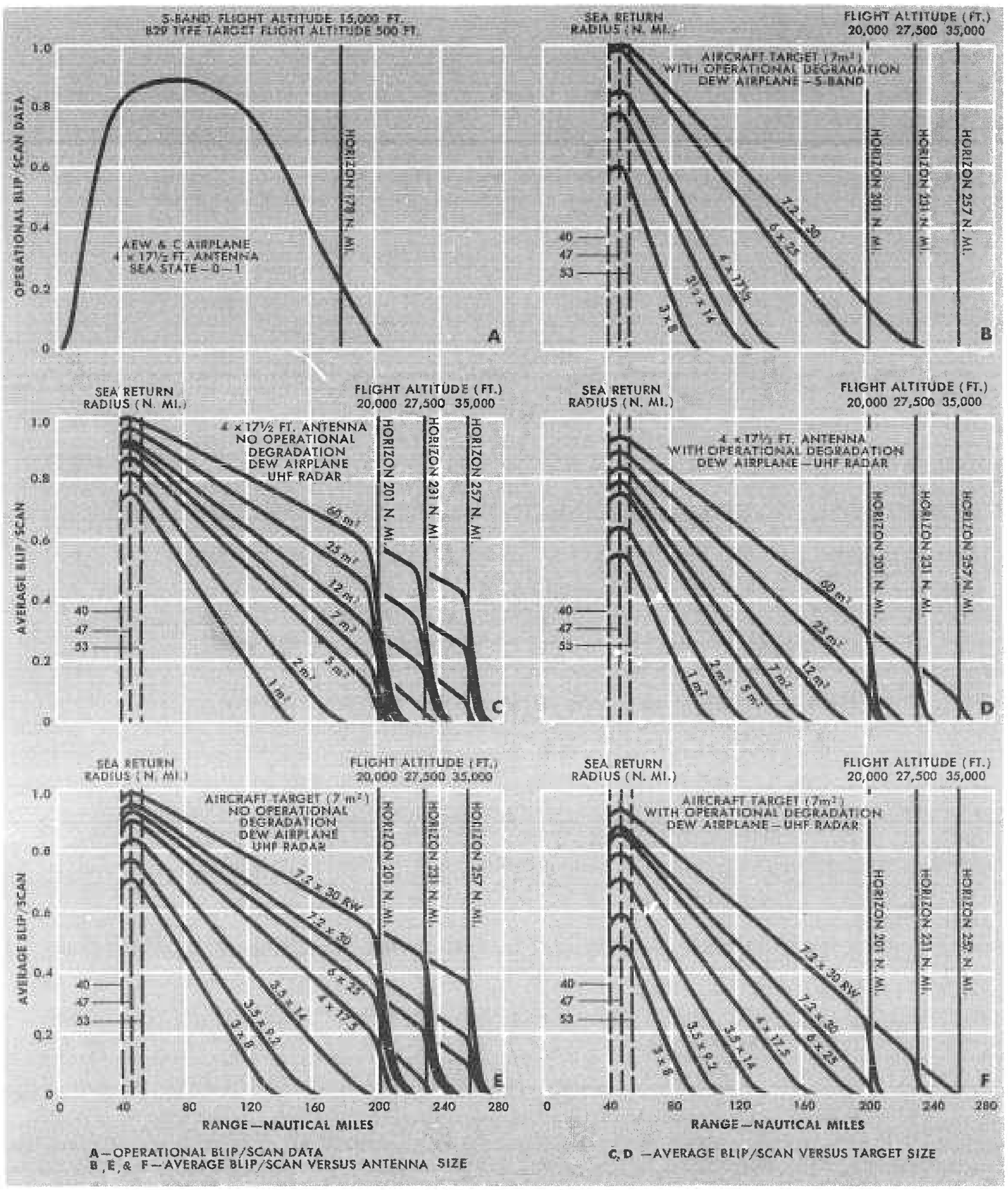


FIGURE II.3 — AVERAGE BLIP/SCAN DATA FOR S-BAND AND UHF RADAR

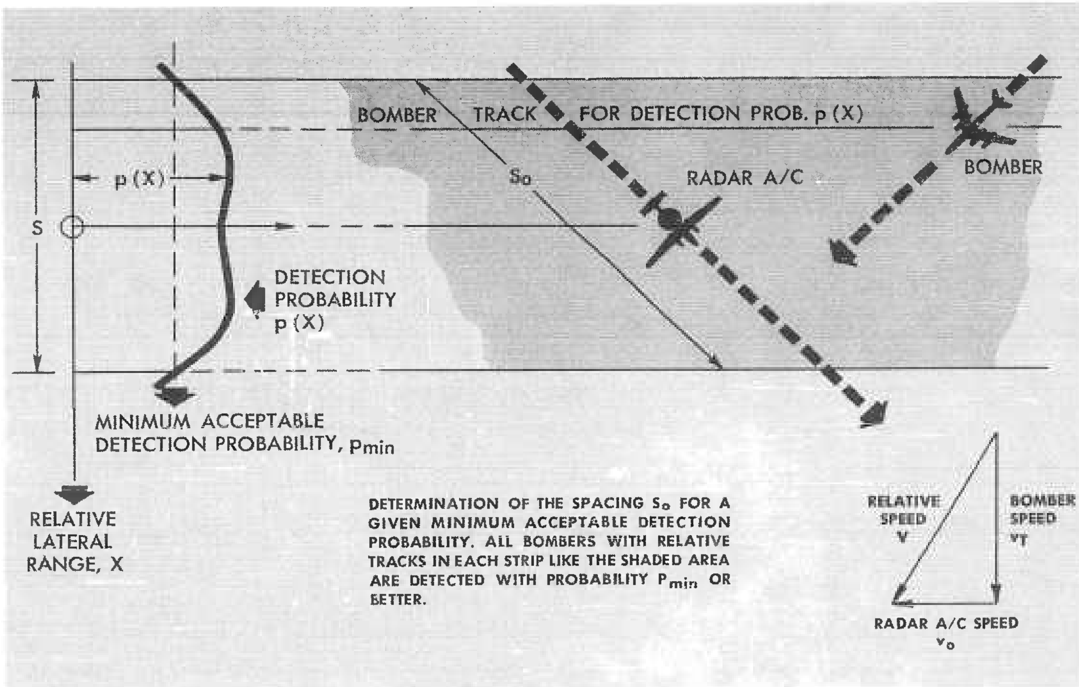


FIGURE II.4—DESIGN OF AIRBORNE RADAR BARRIERS

If the bomber penetrates the barrier perpendicularly with ground speed, v_T, its position on the relative track is given at each time, t, by its distance

$$Y = Y(t) = Y(t_o) - (t-t_o)\sqrt{v_o^2 + v_T^2}$$

from the point of closest approach to the radar. X and Y are rectangular cartesian coordinates of the bomber with respect to a reference system moving with the radar.

The range, r, between radar and target is, at each time t,

$$v = v(t) = \sqrt{X^2 + Y^2(t)}$$

Description of Radar Detection

Conventional radar detection of a target requires (1) that the radar echo produces a blip or blips on the radar (PPI) scope, and (2) that the radar operator notices the blip or blips. In automatic detection devices, operator and scope are replaced or aided by electrical alarm circuits. In either case the detection capabilities of a scanning radar may be described in terms of the following assumptions:

1. Each radar scan is considered as one (independent) look or glimpse at the target; the conditional probability that a specified target at the range, r, will produce a blip in one scan, is called the blip/scan ratio, $\psi(r)$, for the radar and target in question;

2. The operator detects the target during the ith scan with probability p_o (operator factor) if, and only if, the target has produced a blip during the ith scan and also during the k-1 preceding scans, where k is a specified integer. As a rule, experimental data are best fitted by the assumption k=1 (one-blip hypothesis) in the case of airborne UHF radars, and k=2 (two-blip hypothesis) in the case of airborne S-band radars without automatic detection circuits.

Let t_o be the time at which a given bomber comes first within detection range, and let successive radar scans begin at $t=t_1$, $t=t_2$, ... then the average position and range of the target during the ith radar scan is given with sufficient accuracy by the equations with $t=t_i$. The probability of detecting the target during the ith scan (instantaneous detection probability) is:

$$g(r_i) = p_o\ \psi^k(r_i),\quad r_i = r(t_i)$$

(r), and thus also g(r), may depend on the target aspect (target angle) as well as on the target range (see below).

The probability p_i of detecting the target up to and including the ith radar scan (cumulative probability of detection) is obtained by compounding the instantaneous detection probabilities according to the rule

$$p_i = 1 - \left[1-g(r_1)\right]\left[1-g(r_2)\right] \ldots 1-g(r_i),\quad r_i = r(t_i)$$

For a sufficiently large number of scans the cumulative detection probability assumes a limiting value, the total cumulative detection probability p(X) for the relative target track labelled with the lateral range X. Figure II.4 shows a graph of p(X) versus X (lateral range curve).

Choice of Barrier Spacing

The maximum allowable spacing between barrier aircraft is limited by the requirement that the total cumulative detection probability must be at least 0.9 on all bomber tracks; the spacing may be further reduced by additional requirements for communications, height finding, and tracking.

The barrier spacing, S, is the interval of lateral range assigned to each radar aircraft. Figure II.4 shows that the corresponding spacing along the barrier line is $S_o = S\sqrt{1 + \frac{v_o}{v_T}}$, so that radar aircraft flying along the barrier line have a slight advantage over radar aircraft orbiting on-station ($v_o=0$). For all cases considered in the present study S_o, is, however, only negligibly larger than S, so that the approximate relation $S_o=S$ is used.

Values of the barrier spacing $S_o=S$ used in the present study were determined as follows: given a lateral range curve computed for the respective types and flight altitudes of radar and target under consideration, let X be the lateral range at which the total cumulative detection probability p(X) has decreased to the value 0.7. A barrier spacing of 2X would then insure a detection probability of 1-(1-0.7) (1-0.7) = 0.91 for the relative track midway between adjacent radar aircraft. For the purposes of the present study the barrier spacing S was chosen to be somewhat smaller, viz.

1. S=1.9X, for the case of distant early warning only; 1.9X was chosen instead of 2X in order to insure more efficient line-of-sight communications and station keeping.

The value of the operator factor, p_o, determines the build-up rate of the lateral range curves used to obtain each spacing S. The actual operational value for p_o depends on many factors, notably

a. the signal to noise and clutter ratio of the system;
b. the number of targets presented on the scope;
c. the alertness of the human operator; and
d. the method of display, such as conventional PPI or range gated alarm system. See Reference 9.

These factors and others previously mentioned make it difficult to select a single value of p_o that will apply to all systems. For the purposes of this study a value of 0.1 has been used, but values of 0.05 and 0.5 were also examined for their effects.

The blip/scan ratio for each set of parameter values was used to determine corresponding lateral range curves and thus barrier spacings by the method previously outlined. Figures II.5 and II.6 show lateral range curves computed from the corresponding blip/scan curves of Figure II.3 for operator factor p_o = 0.05, 0.1, and 0.5 and for two levels of radar performance.

As previously indicated, aircraft spacing S = 1.9X in a single line barrier provides a minimum cumulative detection probability of 0.91 when X is the lateral range corresponding to a 0.7 cumulative probability of detection. The minimum cumulative detection probability of the barrier can be raised to 0.99 by selecting the value of X corresponding to 0.9. Spacing between barrier aircraft to obtain 0.99 rather than 0.9 need be decreased by 10 per cent or less; force requirements would be increased a corresponding amount.

RADAR SYSTEMS FOR CONTROL CAPABILITY

In the case of search radars, which determine the coordinates of the target in a horizontal plane, the azimuthal resolution is primarily determined by the beamwidth in a horizontal plane. In addition, the accuracy of the other coordinate is established by the range resolution of the radar. Range resolution is considered to be inversely proportional to pulse length in space; bearing resolution is inversely proportional to the corresponding half-power beamwidth. In the case of height-finding radars the elevation resolution is inversely proportional to the corresponding half-power beamwidth. For all types of radar systems considered, radar resolution in range, bearing, and elevation is important for purposes of raid size assessment, identification and control of intercept when the number of bombers in the raid is small. A recent study[10] has shown that where the number of bombers in the raid is large, the difference in the number of bombers surviving attack is not criti-

9. Lincoln Laboratory. *Automatic-Alarm Radar for Project Counter Change.* Final Technical Report No. 24, 4 August 1954. (SECRET)

10. L. H. Wegner. *The Probability Distribution of the Number of Surviving Bombers for the Case of Multipass Attackers.* Rand Corporation, Memorandum No. 1396, 18 October 1954. (CONFIDENTIAL)

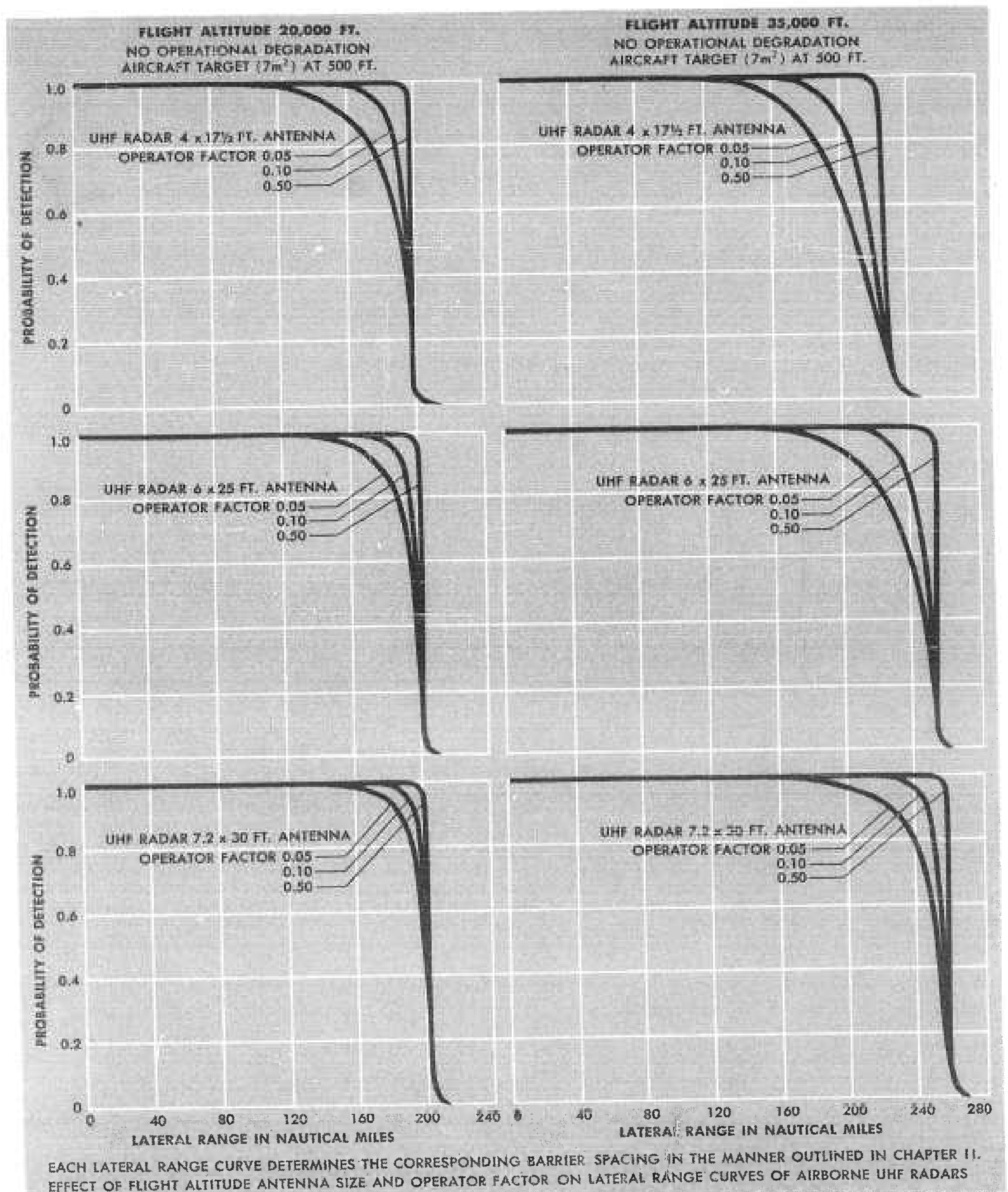


FIGURE II.5—LATERAL RANGE CURVES

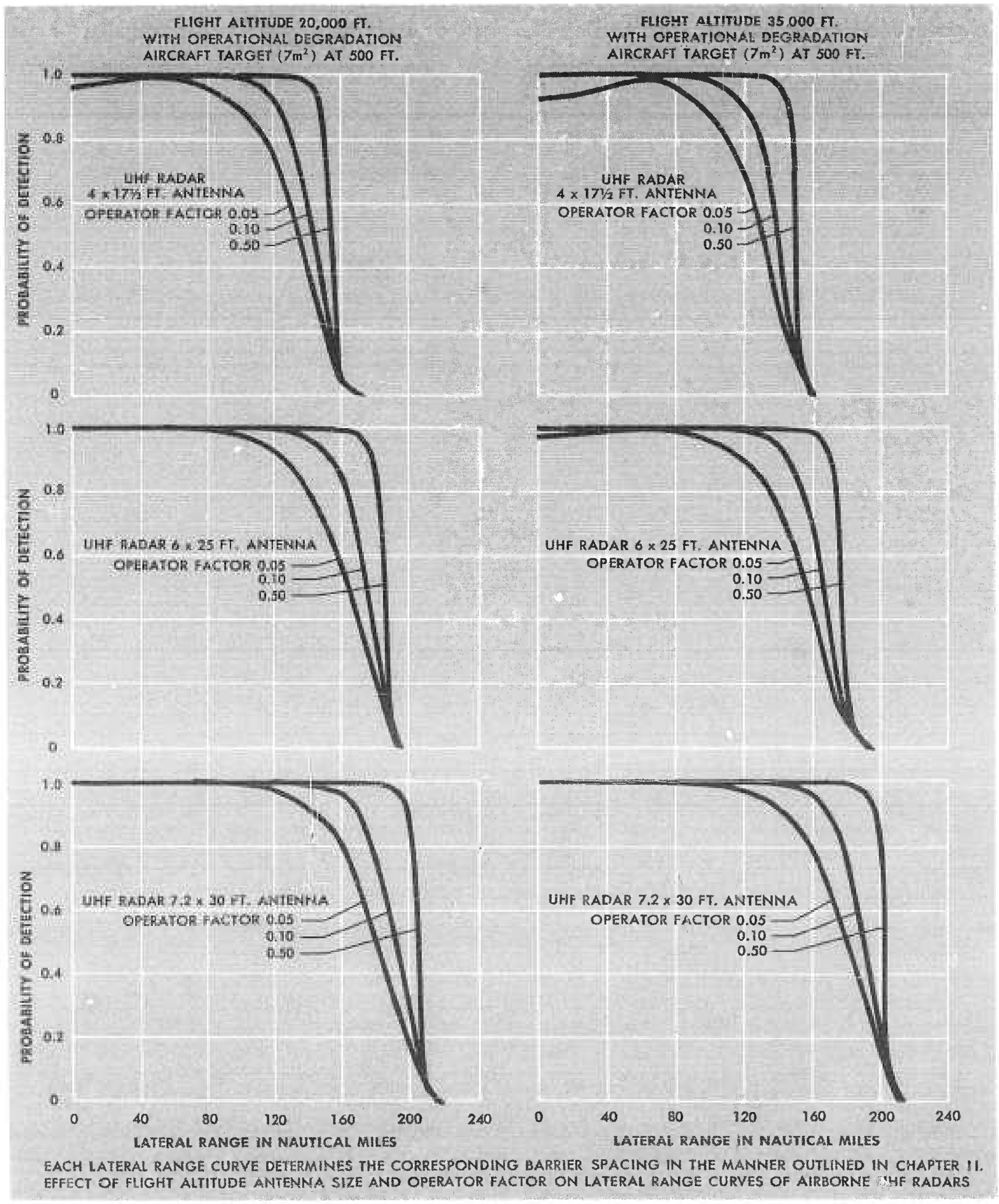


FIGURE 11.6—LATERAL RANGE CURVES

cally dependent on the method of fighter assignment, i.e., either random or uniform assignment resulted in very similar probabilities of bomber survival.

Based on the results of this study (Reference 7) it appears that loose control will enable the kill potential of a DEW & C line to be exploited when the interceptor/bomber ratio is small. Under these conditions, antenna azimuthal beamwidths of 5 to 7 degrees can provide a satisfactory degree of control. These same values of antenna beamwidth may also be adequate for close control based on recent experimental tests of a limited nature made at Lincoln Laboratory. These tests indicated that with a single target and interceptor a close control capability can be achieved with a 9 degree antenna beam radar system. In order to provide a higher degree of close control and better azimuthal resolution for raid size assessment, narrower antenna beams appear necessary. This may be accomplished at UHF by flying larger antenna structures such as might be readily accommodated in an airship.

In the case of the airplane and helicopter, high resolution antennas at UHF do not appear practical for 360 degree coverage. Two solutions to this problem appear to be technically feasible. The first solution involves a reasonably large antenna illuminated by a shorter wavelength radar operating in the vicinity of 35 centimeters to perform the combined search and control function. This would reduce the beamwidth by one-half and thus increase the control accuracy and azimuthal resolution. Height finding could be accomplished by lobe structure methods or by a separate nodding type height finder such as the AN/APS-45. The second solution requires two radars, one operating at long wavelength such as UHF with a conventional antenna for search purposes, and the other operating at a shorter wavelength such as S-or L-band with a stacked beam antenna to provide azimuthal resolution for control and simultaneous target height information. The antennas could be mounted back-to-back or a single reflector could be illuminated by a dual frequency feed.

For control, the third coordinate, altitude, must be determined. As has been previously indicated the height finding function may be incorporated in the search radar system, or can be provided by a separate height finding radar. For nodding type height finding radars the elevation beamwidth should preferably beaabout 0.5 degrees or at most 1.75 degrees to obtain usable elevation resolution. The azimuthal beamwidth

of nodding type height finding radars should normally exceed the azimuthal beamwidth of the associated search radar by a factor of 1.5 or more to facilitate picking up air targets located in range and bearing by the search radar. For stacked beam combination search and height finding radars the elevation beamwidth of each individual lobe should not exceed 3 to 4 degrees in order to provide useable interpolation accuracy between beams. Both types of radar systems have been included in the analyses.

The display of the target coordinates to the operator with present day equipment is not efficient. The weight of the equipment and number of operators required is excessive for the number of intercept tracks that can be handled. Based on limited experience, it appears that two simultaneous intercepts per display console and operator are about the maximum that can be handled. For the time period of this study it is assumed that more efficient equipment and techniques will make it possible to handle six simultaneous intercepts per console and operator. This may be accomplished by development of manually aided tracking consoles and associated course computers similar to the General Electric AN/GPA-37. The maximum required track handling capacity of an airborne search and control system will depend on the need for close or loose control asaa function of:

1. estimates of raid size and their distribution in space;
2. the accuracy of target coordinates provided by the airborne search and control system; and
3. the number of interceptors that can be made available.

With this type of display and course computer the number of operators and weight of equipment can be reduced for the same number of simultaneous intercepts.

As in the case of search radars, the accuracies with which height information can be obtained on aircraft targets from airborne radar platforms is a function of many factors, such as radar resolution, antenna stabilization, effects of surface reflections, nonstandard refractive conditions, and others.

Due to the qualitative nature of information covering the influence of surface reflections and nonstandard refraction, it was necessary to assume an average value of 0.4 for the surface reflection with conditions of standard refraction.

Under these conditions the accuracies obtainable will be determined primarily by the range and beam resolution for a nodding beam type of height finding radar. With radars of the stacked beam type, height finding accuracy depends on other components in the system. The accuracy obtainable with lobe structure methods of height finding is largely dependent on specular reflection from the sea surface; these methods may be useful only with longer wavelength radars.

The accuracies for nodding height finders are approximately 0.2 beamwidth. In the case of stacked beam radars the accuracies may approach 0.1 beamwidth. The multi-lobe techniques provide accuracies of the order of 0.5 lobe width. Greater accuracies may be possible if the pulse time difference or frequency modulated lobe structure techniques work out in practice.

With all of these methods there exists a minimum target elevation below which accurate height determination cannot be obtained because of image aberrations and clutter. This lower altitude is limited to approximately 0.5 beamwidth for the nodding and stacked beam systems, and to the elevation angle of the lower lobe above the sea surface in the case of multi-lobe methods.

Combination search-height radar systems which make use of stacked beams and lobing techniques were generated with characteristics similar to those listed in Figure II.1. The weight and drag associated with these airborne radar systems have been taken into account in the analyses.

One of the candidate systems is the AN/APS-45, currently employed in AEW & C aircraft. The characteristics of this height-finder radar are as follows:

wavelength = 3.2 cm
antenna size = 2.5 x 7 feet
antenna gain = 39 decibels
vertical beamwidth = 1.2 degrees
horizontal beamwidth = 3 degrees
peak power = 450 kilowatts
pulse length = 1.8 microseconds
pulse repetition frequency = 450 cycles/second.

For this study the detection range capabilities of the AN/APS-45 type of height finding radars for a performance level 2 are assumed to be 75 nautical miles. For combination search - height finding systems a value of 0.7 of search range results in a value of barrier spacing S = 1.33 times the lateral range X for a probability of detection of 0.7, in order to insure proper height finding and tracking range for control purposes.

Another important factor which should be considered in the design of airborne search and control systems is the detection and lock-on range of the piloted or unpiloted weapon in terms of elevation and azimuthal capture coverage provided by the acquisition radar. If the elevation coverage can be increased without compromise of detection range, the height finding accuracy requirements of airborne search and control systems could be reduced. Actually, the best height finding accuracies that the state-of-the-art can provide are so marginal that other steps must be taken to achieve a satisfactory capability.

Improvements in radar system performance which the state-of-the-art could provide and which might affect the selection of an optimum aircraft are listed in the following major categories:

1. Increased transmitter power which might provide 10 to 40 per cent increase of detection range. This is the brute force solution and involves considerable increase in weight, space and primary power.
2. Lower receiver noise figure which could provide 5 to 25 per cent increase of detection range. A decrease in receiver noise figure is the most desirable way of providing increased performance without weight or space penalty.
3. More effective clutter suppression circuits which will be effective against sea, ice and land clutter. Improved clutter circuits would increase the area within search coverage that could be utilized for control of intercept. Effective clutter and noise reduction should make it possible to use automatic operator alerting circuits to increase the probabilities of detection.
4. Improved types of antennas, such as the retarded wave type which may give equivalent radar performance with lower weight and aerodynamic drag penalty to the aircraft.

5. Increased control capabilities resulting from track-while-scan or manually aided tracking techniques in combination with course computers to provide vectoring information to interceptors by a digital data link.

Recapitulation

The following summarizes the analysis of airborne radar discussed in this chapter. The principal factors and parameters which influence the operational performance capabilities of airborne radar systems in DEW and DEW & C barrier operations are restated.

1. Wavelength

A range of wavelengths from 10 to 150 centimeters has been analyzed. Experimental test data of a limited nature are available covering narrow bands in the vicinity of 10 and 70 centimeters. From these data and other important considerations, it is concluded that the longer wavelengths, such as 70 centimeters, are more effective for the airborne search function.

2. Radar Design Parameters

Radar design parameters such as peak power, receiver noise figure, pulse length, and pulse repetition frequency are examined. It is concluded that these radar design parameters are essentially fixed by the state-of-the-art and mission functions. Antenna gain, which depends on wavelength and antenna size, is the parameter which is varied in order to determine radar system capability, flight altitude, and barrier aircraft spacing for a desired probability of detection.

3. Antennas

The gain, beamwidths and resulting physical size of the antenna have the greatest effect on airborne radar system performance. The size of antennas for search and control with 10.7 centimeter radars is limited to 25 feet in the azimuth plane due to stabilization problems, and the smaller number of pulses per beamwidth on target which larger antenna aperture would provide with an acceptable scan rate and pulse repetition frequency. Otherwise the radar beam becomes so narrow that it cannot be adequately stabilized on an airplane platform, and the number of pulses per beamwidth on target with a suitable scan rate and pulse repetition frequency becomes too small to provide the desired information rate and range capability. This antenna size restriction does not necessarily apply to longer wavelength radars.

With shorter wavelength radars, a shaped reflector to provide an approximate cosecant-squared pattern, or a multiple-feed stacked-beam antenna system, yield the desired vertical coverage. With 72 centimeter radars the vertical antenna aperture should not exceed 10.5 feet. Apertures of less than 4 feet vertical dimension which give beamwidths of more than 40 degrees, are considered too wasteful of power to be considered.

The development of retarded surface wave antennas may make it possible to reduce the vertical and azimuthal apertures for the same beamwidths, thus providing an antenna and radome structure for airplane and helicopter use with less aerodynamic drag.

For the search radar systems under consideration, the azimuthal beamwidth of the antenna essentially determines the azimuthal resolution. Narrow beamwidths or high resolution are beneficial first, in discriminating between targets at the same range; second, in the MTI problem, by reducing the clutter area illuminated by the beam; and third, in increasing the systems ability to provide close control of weapons.

It is concluded that most of the antenna shapes listed in Figure II.2 do not provide an ideal aspect ratio. Conventional antennas with aspect ratios greater than 3:1 become increasingly difficult to illuminate efficiently. In order to obtain a desired elevation coverage and azimuthal beamwidth, or to have the antenna conform with the aerodynamic shape requirements of radomes, these compromises with preferred antenna design criteria are necessary.

4. Blip/Scan Ratios

The blip/scan ratio is descriptive of the ability of the radar system to provide a usable return signal from the target. The more important factors which determine the blip/scan ratio or radar system capability are the following:

1. Radar system design parameters
2. Antenna gain
3. Horizon limitations due to flight altitude of radar and target
4. Effective reflecting area of the target
5. Degradation of performance due to lack of maintenance, and
6. Effect of refractive anomalies and ducts.

A basic assumption is that the flight altitude of airborne search systems should be that altitude which gives a radar horizon distance equal to the mean value of the blip-painting range of the radar on specified aircraft targets flying at low altitude.

The effective radar reflecting area of the primary target aircraft (jet bomber) has been given a value of 7 square meters as a reasonable value for random penetrations of the search zone.

Loss of performance due to maintenance degradation affects the operational performance of airborne radar systems. By giving proper emphasis in design to the various factors which influence the operational reliability, it is believed that radar systems can be developed which will provide round-the-clock reliability with high performance if adequately maintained.

For this study two levels of performance have been selected to bracket the expected operational performance. Level 1 represents a radar system capability provided by a high standard of maintenance and equipment adjustment. Level 2 represents a radar system capability degraded by lower maintenance standards and incorrect equipment adjustment.

Anomalous propagation (nonstandard refraction) at times exerts a profound effect on radar coverage. This implies that the effectiveness of an airborne radar barrier will vary as a function of weather due to bending or trapping of radiated energy in certain altitude layers. The effect of nonstandard refraction will also introduce errors in height finding which may be serious.

Two possible methods of reducing the effects of refractive anomalies have been considered. These are: (1) increased effective radiated power, and (2) higher flight altitudes than have been previously considered for DEW operations.

The effects of refractive anomalies on the spacing of aircraft and detection probabilities of barrier operations, if effective MTI is not achieved, are discussed in Appendix A.

Blip/scan curves for the various radars with characteristics similar to those specified in Figure II. 1 were computed by extrapolation of 10 and 70 centimeter experimental test data for several flight altitudes, target reflecting areas, antenna sizes, and operational degradation.

It is concluded that in order to realize the maximum capabilities of longer wavelength radar systems with double delay clutter-lock MTI it would

be essential to fly the largest antenna compatible with aircraft altitude and range performance in order to reduce force requirements. Flying the airborne system above the altitude at which refractive anomalies occur appears promising and feasible providing the airborne system is suitably designed for such operational altitudes and the adverse effects of sea clutter are reduced sufficiently by an effective MTI system.

5. Search Theory

Conventional search theory is used to combine the predicted blip/scan data with the performance of the operators in a quantitative relationship. This relationship includes an estimate of p_o, the probability that the operator detects a target. The value of the operator factor, p_o, determines the build-up rate of lateral range curves which are used to obtain barrier spacing S.

Values of barrier spacing S were determined from lateral range curves computed for the respective types and flight altitudes of radar and target under consideration. Let X be the lateral range at which the total cumulative detection probability p(X) has decreased to 0.7. In order to insure more efficient line of sight communications and station keeping, S was chosen as $S = 1.9X$.

The minimum cumulative detection probability of the barrier can be raised to 0.99 by selecting the value of X corresponding to 0.9. Spacings between barrier aircraft to obtain 0.99 rather than 0.9 need be decreased by 10 per cent or less; force requirements would be increased a corresponding amount.

6. Radar Systems for Control Capability

For all types of radar systems considered with control capability, radar resolution in range, bearing, and elevation is important for purposes of raid size assessment, identification and control of intercept.

For the time period of this study, it is assumed that more efficient equipment and techniques, such as manually aided tracking and course computers will make it possible to handle six simultaneous intercepts per console and operator.

The maximum required track handling capacity of an airborne search and control system will depend on the need for close or loose control as a function of:

1. estimates of raid size and their distribution in space;
2. the accuracy of target coordinates provided by the airborne search and control system; and
3. the number of interceptors that can be made available.

As in the case of search radars, the accuracy with which height information can be obtained on aircraft targets from airborne radar platforms is a function of many factors, such as radar resolution, antenna stabilization, surface reflections, nonstandard refractive conditions, and others.

For combination search-height finding systems a value of barrier spacing, $S = 1.33X$ is used to insure proper height finding and tracking range for control purposes.

Another important factor which should be considered in the design of airborne search and control systems is the detection and lock-on range of the piloted or unpiloted weapon. If the elevation coverage can be increased without compromise of detection range, the height finding accuracy requirements of airborne search and control systems could be reduced.

The accuracies which might be obtained with three types of height finding radars are discussed. It is concluded that the best height finding accuracies that the state-of-the-art can provide are so marginal that other steps must be taken to achieve a satisfactory height finding capability.

Other factors which have been considered, but have not been quantitatively evaluated in terms of their possible effect on radar search and control systems are:

1. the effects of enemy use of ECM;
2. the effects of refractive anomalies;
3. the effect of radar system reliability on the over-all weapon system's reliability;
4. the effect of environmental conditions in aircraft and their influence on the performance of the operators;
5. the effect on probabilities of detection and control capability due to multiple targets;
6. the identification problem.

The importance of adequate communications and navigation to the search and control functions of DEW barrier operations are discussed in Chapter III.

CHAPTER III

COMMUNICATION AND NAVIGATION SYSTEMS

INTRODUCTION

To cope with possible attack by enemy aircraft it is axiomatic that observation of such attacks must be made from positions far enough away from vulnerable targets to provide time needed to alert defenses and to prepare a countermove. The primary objectives of a DEW system are to collect and transmit information on enemy penetrations of prescribed geographic defense zones[11]. Even if a suitable airframe and a reliable search radar are available, these objectives can only be accomplished if there is a communication system to transmit information and a navigation system to position the search aircraft on the DEW barrier.

In addition to the primary DEW functions, the system may be expanded to include the direction of fighter aircraft to intercept enemy bombers within the advanced zones (DEW & C). This additional capability places an even greater importance on the communication and navigation systems.

SCOPE

Deficiencies in communication ranges and errors in navigation could materially penalize a DEW system. In treating the communications and navigation problems, therefore, the reliable transmission ranges of communications systems will be explored as well as the ability of navigation systems to control transit to barrier stations and positions in the barrier.

Figure III.1 shows a simplified schematic diagram of an airborne DEW system off the continental shores. Shaded areas are detection contours attained by the particular radar equipment in use. From the diagram it can be seen that the station keeping or position schedules of DEW aircraft must be maintained to avoid gaps in the radar coverage through which undetected

11. *Some Aspects of Airborne Early Warning and Continental Defense.* Lockheed Report 9740. Military Operations Research Division, Lockheed Aircraft Corporation, 15 April 1954. (SECRET)

enemy penetrations could be made. The indicated communication paths show possible transmission circuits and do not represent any particular system. The aircraft bases at the terminals of the DEW barrier serve as clearing stations for communications to the area defense commanders.

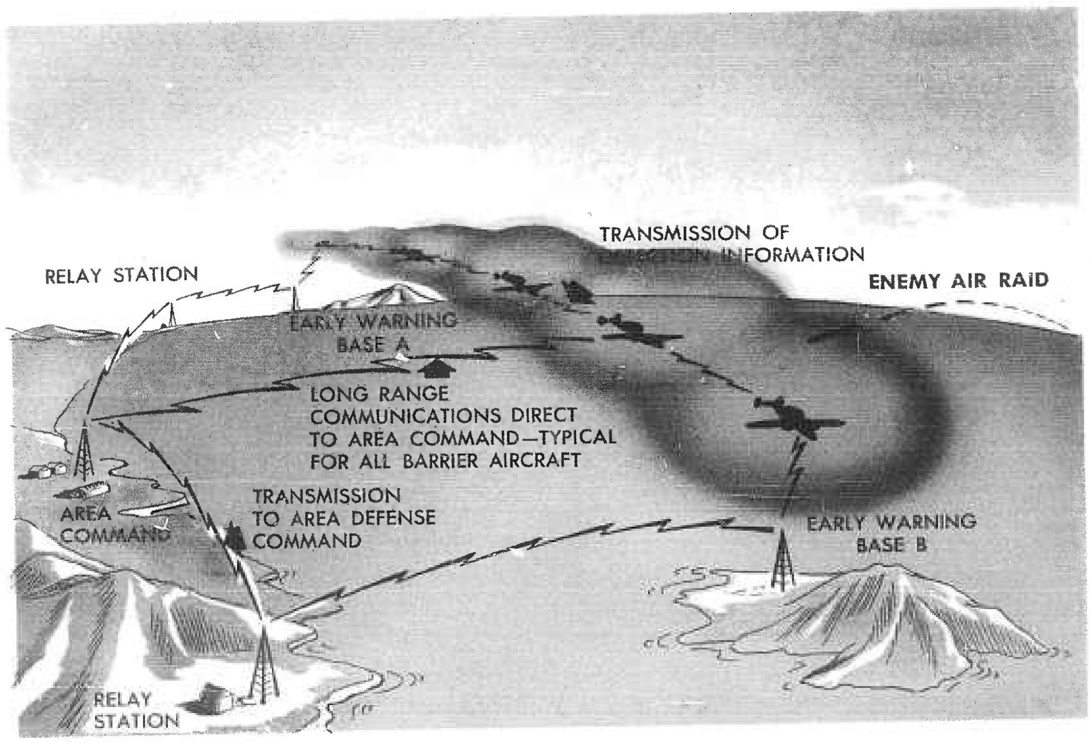


FIGURE III.1—EARLY WARNING LINE

Since the airplane, the helicopter and the airship are utilized differently in the DEW barriers, any discussion of communication and navigation must consider these differences. The tactical models employing these aircraft are analyzed in Chapter IV.

COMMUNICATIONS

Methods

To approach the problem with some perspective, all conceivable methods of communication involving transfer of energy were examined. It was concluded that electromagnetic radiation despite all its problems and

attendant shortcomings appeared to be the only method of communication which would provide the necessary propagation velocity, information rate, and coverage.

A review of conventional and currently available airborne communications equipment indicated that it would be difficult to achieve the communications reliability[12,13] demanded by early warning.

In addition, consideration has been given to recently proposed systems, such as reflection from meteor trails, ground wave propagation, and tropospheric scattering. There is insufficient information at this time to evaluate these methods for application to airborne equipment.

Requirements

Study of the requirements for distant early warning indicates that the major problem in communication is reliable propagation (References 14 through 18). The emphasis of this chapter will therefore be placed on the propagation problem. As previously mentioned, radio communications need examination in an effort to determine what spacing limitations, if any, are imposed by the communications link. Range limitation would be reflected in reduced spacing of the barrier aircraft.

In the discussion of radar ranges in Chapter II it was indicated that a range overlap would exist between adjacent radars. The degree of overlap places adjacent aircraft in radio line of sight. This being true, there are three essential considerations in determining the propagation frequency (Reference 19). These consist of:

1. The frequency

12. *Future Naval Communication, Volume I, PRU.* Institute of Cooperative Research, Johns Hopkins University. May 1951. ONR Contract N6onr 24311. (SECRET)

13. *Interim Report on Project Cosmos.* Bell Telephone Lab., May 1954. (SECRET)

14. K. A. Norton. *Transmission Loss in Radio Propagation. Proc. IRE* January 1953. (UNCLASSIFIED)

15. F. E. Terman, *Radio Engineering Handbook.* 1st Edition. McGraw-Hill Book Co., Inc., 1943. (UNCLASSIFIED)

16. D. E. Kerr. *Propagation of Short Radio Waves.* M.I.T. Radiation Lab., Series. Vol. 13; McGraw-Hill Book Co., Inc., 1951. (UNCLASSIFIED)

17. H. R. Reed, C. M. Russell, *Ultra High Frequency Propagation.* John Wiley & Sons, Inc., New York, 1953. (UNCLASSIFIED)

18. F. E. Terman. *Radio Engineering, 3rd Edition.* McGraw-Hill Book Co., Inc., 1947. (UNCLASSIFIED)

19. J. R. Rodgers. *Propagation Considerations. Air-to-Air Communication.* Report LR 10592; 14 April 1955. Lockheed Aircraft Corporation, Burbank, California. (UNCLASSIFIED)

2. The antenna configuration and its location.
3. The propagation, power and bandwidth.

Frequency

A survey of the radio frequency spectrum was made to determine, if possible, a frequency band most suitable to this operation. At frequencies below 60 Mc the following become critical:

1. Antenna sizes become large for efficient power radiation.
2. Sporadic ionospheric reflections and magnetic disturbances cause serious transmission fading.
3. Interference due to atmospheric noises becomes pronounced.
4. Bandwidth allocations present problems on the HF band.

Above 3000 Mc the following phenomena become critical.

1. Cosmic and receiver noise
2. Atmospheric ducting
3. High atmospheric attenuation
4. Scattering and absorption due to precipitation

This brief review of the radio spectrum indicates that the best compromise lies in the region between 60 and 3000 Mc.

Antenna

In the 2000 to 3000 Mc region of the radio spectrum, antennas with the required beamwidth, gain, and power handling capacity are of such size that they do not present an insurmountable problem for aircraft installation. This 2000 to 3000 Mc region is still in the preferred portion of the frequency spectrum which was concluded to be between 60 and 3000 Mc. Vertical beamwidth can be designed into the antenna to eliminate the need for vertical stabilization.

Power and Bandwidth

In view of the reliable communication ranges to be attained, and of present limitations on airborne power, it appears logical to use a directive antenna instead of an omni-directional radiator. The calculations for the power required for transmission between DEW aircraft are based on Reference 14. An accounting is made for losses in power from the input to the

transmission line of the transmitting antenna over the transmission path and through the receiving antenna and receiver. In Figure III. 2 the sloping lincs indicate the attenuation, in standard atmosphere, of the transmission path for the 2000 and 3000 Mc frequencies. The broken horizontal line labeled "threshold of reception" includes:

1. Transmission line losses to the transmitting antenna.
2. Efficiency of transmitting and receiving antenna.
3. Transmission line losses to receiver
4. Receiver losses

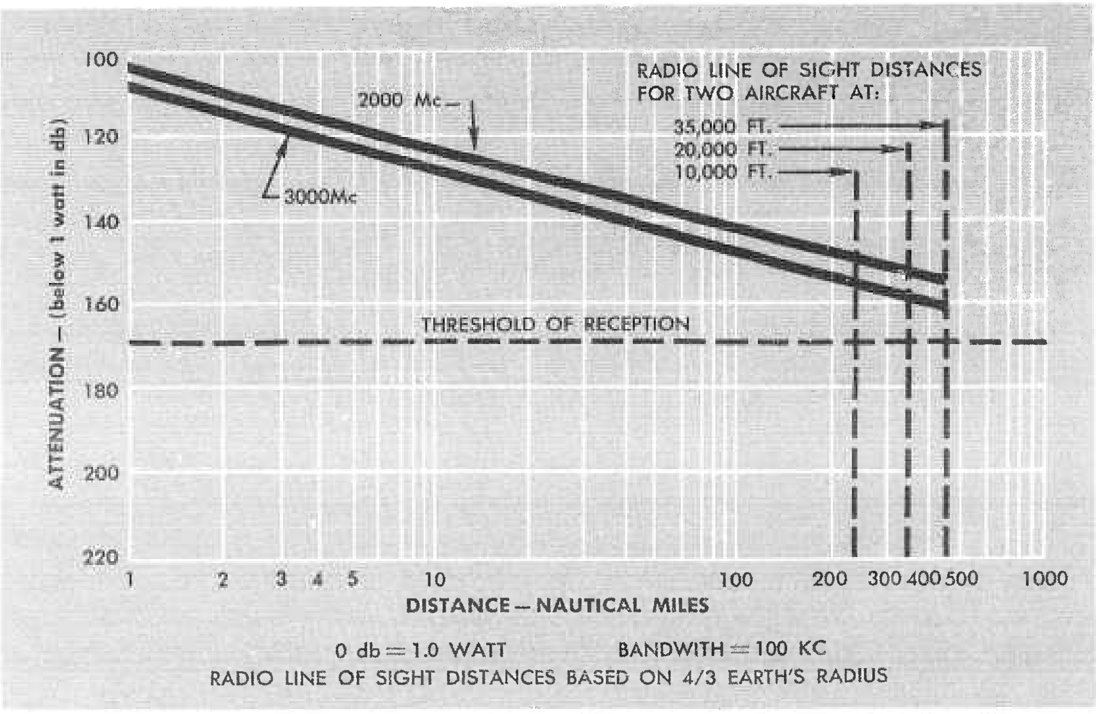


FIGURE III.2—ATTENUATION VS. DISTANCE FOR LINE OF SIGHT TRANSMISSION

With a 1-watt reference level the power available above the threshold of reception is approximately 9 db for 3000 Mc and a bandwidth of 100 Kc at the 465 nautical mile distance. In order to provide a high signal to noise ratio for satisfactory transmissions through the interference regions and ducts, a 40 db margin is considered necessary. The difference between 40 db

and 9 db is the 31 db increase required in transmitted power over the one watt reference, or approximately 1000 watts. The figure of one kilowatt represents the order of power input to the antenna feed of the transmitting antenna for reliable DEW communications.

Proposed System

From investigations of frequency, power, antenna pattern and size, it was judged that beamed high-frequency propagations showed the most promise of providing a high reliability path for early warning communications.

To put these conclusions into practice, two antennas capable of being oriented in bearing will allow each aircraft to train its antennas on adjacent aircraft. These antennas can be servo-controlled to automatically maintain proper directivity when they have been locked on the signals radiated by antennas of adjacent aircraft. The resulting arrangement becomes in effect an airborne microwave system. This, briefly, is the method proposed to overcome the propagation difficulties of the primary communications system for early warning.

Back-Up Systems

As back-up protection against severe high frequency fading and disturbances, time and frequency diversity techniques can be used; in addition, MHF communications can be incorporated utilizing a trailing wire antenna.

Communications for DEW & C

To provide the DEW aircraft with a control capability, a separate omnidirectional antenna is required. This antenna will enable the DEW & C aircraft to communicate with the interceptor during the control phase of the operation. Based on the antenna and power of the primary communication system the transmission power loss due to directivity is approximately 18-20 db. Because the control ranges are about half the DEW & C aircraft spacings, the propagation for control should be as reliable as the primary communications system. A high power is necessary to overcome the deficiencies of the interceptors' antenna pattern.

NAVIGATION

Methods

A systematic review of the existing techniques (see References 20 through 25) reveals that they can be conveniently grouped into two categories, self-contained navigation systems and external reference navigation systems.

Self-Contained (SC) Systems

Representative SC navigation techniques are:

1. Celestial navigation
2. Inertial navigation
3. Ded reckoning navigation
4. Electronic doppler navigation

Automatic systems for navigation have been designed which use these techniques either singly or in combination.

External Reference (ER) Navigation Systems

The majority of ER navigation systems are electronic in nature. The systems use surface broadcasting with lightweight receivers and computers to furnish position and azimuth reference indications. A representative list of long range ER navigation systems follows:

1. Loran
2. Radux
3. Navarho
4. Consol
5. L.F. direction finding equipment

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20. *Long Range Navigation NAVEXOS P-645.* Office of Naval Research, Dept. of Navy, Washington, D.C., July 1949. (SECRET)
21. *Symposium on Self Contained Navigation Systems.* Sponsored by Research and Development Board. Navigation Technical Group at University of California, Dept., of Engineering, Los Angeles, Calif. 9-10 Feb. 1953. (SECRET)
22. L. N. Ridenour, *Radar System Engineering.* M.I.T. Rad. Lab. Ser., Vol. I: McGraw-Hill Book Co., Inc., 1947. (UNCLASSIFIED)
23. J. S. Hall. *Radar Aids to Navigation.* M.I.T. Rad. Lab. Ser., Vol. 2; McGraw-Hill Book Co., 1947. (UNCLASSIFIED)
24. J. A. Pierce, A. A. McKenzie, R. H. Woodward. *Loran*; M.I.T. Rad. Lab. Ser., Vol. 4; McGraw-Hill Book Co., Inc. 1948 (UNCLASSIFIED)
25. James Holahan. *Navarho System — Near Final Evaluation.* Aviation Age, March 1955. (UNCLASSIFIED)

Well-known representations of line-of-sight ER navigation systems are:

1. VOR
2. Tacan
3. Navigation radar

The curves of Figures III. 3 and III. 4 showing the relationship between navigation errors with range. The curves represent average estimated performance of these systems when such systems are permitted by environment to make measurements peculiar to their operation. For example, the curve for "celestial fixes" is based on unobstructed, undistorted sightings of stars.

Requirements.

In the barrier operation the navigation system must provide station keeping information so that there are no gaps in radar search coverage or line-of-sight communications. Information must also be provided for transit navigation to and from the early warning stations.

Proposed System

A review of existing navigation techniques made it evident that the early warning aircraft may navigate with its communications system.

In the previous section dealing with communications it was determined that the primary mode of communication in the early warning line should be beamed line-of-sight RF signals. With two beam antennas, servo-controlled to automatically track the antennas of adjacent aircraft, the airborne microwave chain has the ability to make range and bearing measurements, in addition to its communications capability. Applying this concept to the early warning line, the navigation system required to maintain spacing and alignment may be formulated.

After reaching station altitude the DEW aircraft aligns itself with the adjacent aircraft, utilizing its NAVACOM (Navigation and Communication) system. Through its communications channels, range and bearing of adjacent aircraft are relayed to the barrier control station on the early warning base, see Figure III. 1. At the control station a plotting board record of aircraft spacing and alignment is maintained. From this record the barrier commander can issue orders correcting the alignment and spacing to minimize accumulations of spacing errors in any sector of the line.

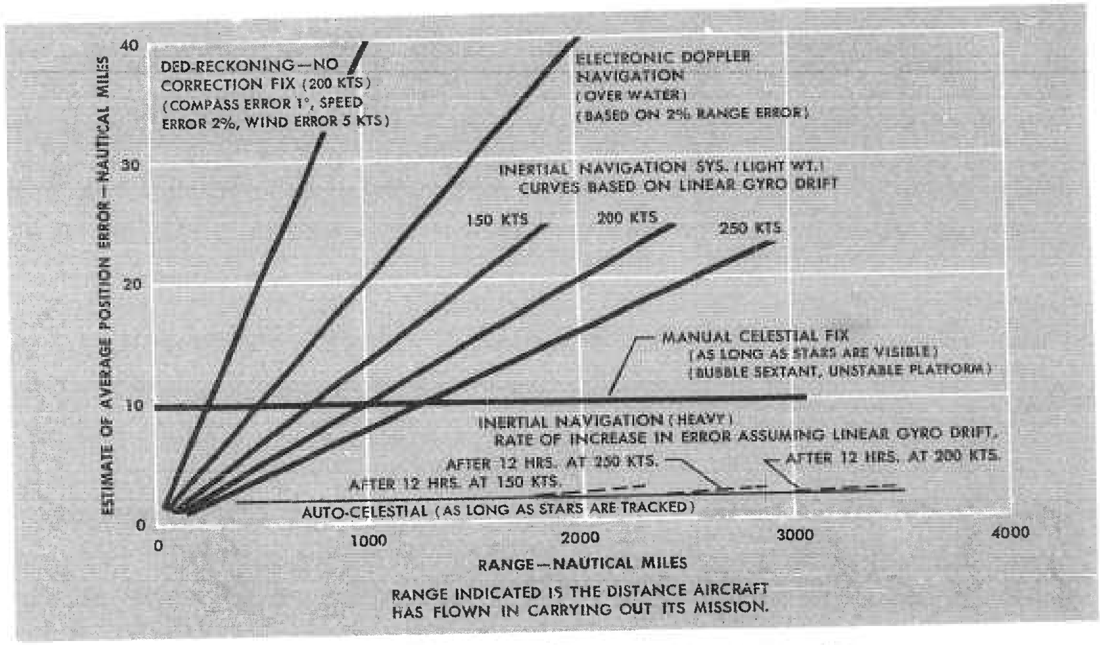


FIGURE III.3 — SELF-CONTAINED NAVIGATION SYSTEMS

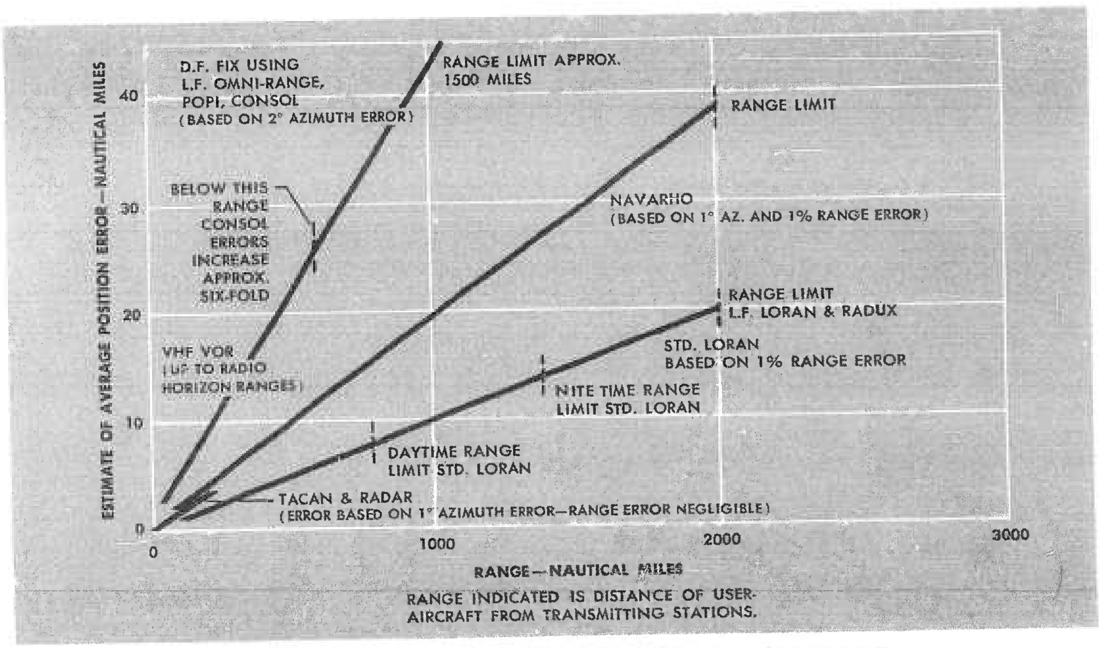


FIGURE III.4 — EXTERNAL REFERENCE NAVIGATION SYSTEMS

Since the steering information of the barrier aircraft comes from a self-contained navigation system, the alignment adjustment orders issued by the barrier commander take the form of corrections to the position indications of the self-contained systems. A lightweight doppler navigator equipped with a computer and a DRT would be well suited for a self-contained system. The doppler computer should be flexible enough to accept airspeed data in the event the doppler velocity measuring equipment fails. The self-contained systems will be needed by the airplane and airship but not by the helicopter. To keep the military load in the helicopter to a minimum the NAVACOM information will be relayed from the helicopter to its basing vessel, which will correct its surface position. The helicopter, in aligning itself on the adjusted position of the basing vessel, then corrects its position in the airborne line. This is a continuous process and results in the maintenance of suffucient accuracy for the helicopter position on the DEW line.

To derive a measure of the alignment and spacing error a 2400-mile, straight-line barrier between two geographic points was assumed. A nominal aircraft spacing of 400 miles was used. Figure III.5 shows the geometry of the barrier line with the correct positions, the actual positions and reported positions. The difference between the actual position and reported position constitutes the navigation error. By providing a sector scan feature into the antennas it appears that the servo-alignment of two facing antennas can be maintained to a sum of one-half to one degree. If the link is assumed to have resolution capability of 1° in bearing and 1 per cent in range, the actual positions will lie in an elliptical area centered on the correct positions. (Reference 26). The location ellipses and their dimensions in nautical miles are shown in Figure III.5. As might be expected, there is a noticeable reduction of error as the aircraft approach land-based reference points. These navigation accuracies appear to be sufficient to maintain the radar and communications integrity of the early warning barrier.

Transit to Station

The initial transit to station for the helicopter is primarily a vertical ascent from the basing vessel to operational altitude. During ascent, the

26. J. E. Walsh. *Evaluation of Errors in Estimating DEW AIRBORNE Vehicle Locations.* L-273 Memo No. 107, Military Operations Research Division, Lockheed Aircraft Corporation. 22 March 1955. (CONFIDENTIAL)

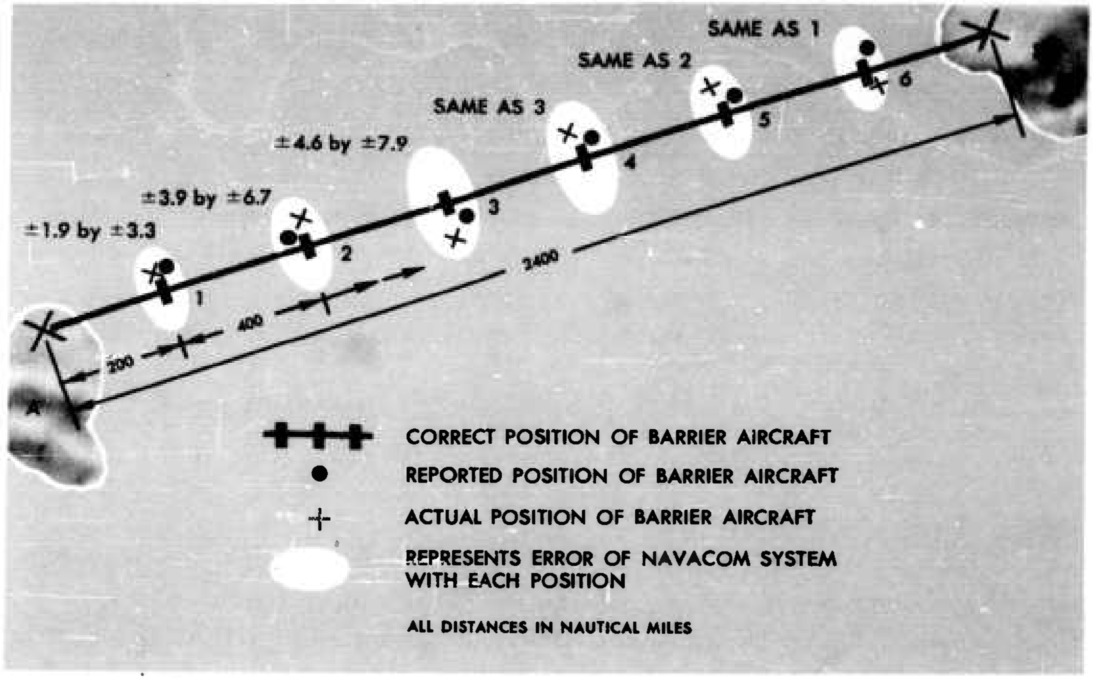


FIGURE III.5 — EARLY WARNING LINE AND CALCULATED ERRORS OF NAVACOM SYSTEM

helicopter crew maintains a fix on the basing vessel, utilizing the search radar as a navigation radar. The basing vessel's radar also, as a safety measure, checks the ascending helicopter. After reaching altitude, the helicopter aligns itself in the barrier using the NAVACOM system.

Transit to station for the airplane is fundamentally similar to the helicopter. During its ascent the airplane maintains radar fixes on its base. After reaching altitude it aligns itself on station, using the NAVACOM system.

There do not appear to be any stringent requirements for the accuracy of airship transit navigation. Navigation need be only accurate enough to bring the transiting airship within the radar surveillance of the airship it relieves; close control techniques may then be used to bring it accurately into the NAVACOM controlled line. A transponder beacon system will aid in the identification of the relieving airship by the airship on station.

Thus far only the navigation needs for barrier operation have been discussed. The usual manual celestial navigation equipment as well as those for

altimetry should be carried for back-up systems. Other equipments which give navigation data peculiar to general tactical doctrines, such as homing beacons, should, of course, be carried.

Failures Affecting Communications and Navigation

Up to this point the discussion of the communications and navigation system has assumed ideal operation. To bring the study closer to actual operations three types of failures will be examined for effects on the barrier. They are:

1. Aircraft failure which will cause a radar gap in the barrier and break the NAVACOM chain.
2. Failure of the NAVACOM equipment only leaving radar and airframe operational.
3. Failure of the Radar.

Airplane System Failures

Unairworthiness of an airplane on station will compromise the radar coverage, communications and navigation. The most expeditious way to fill the gap caused by the faulty airplane to move up the adjacent airplanes to fill the gaps progressively until the gap remaining next to the base is filled by a ready relief dispatched from it. By proper coordination the gaps can be filled in little over an hour by this process. During this readjustment period the airplanes will operate on their self-contained doppler systems; fly courses and altitudes established by doctrine. The navigation errors during this period should not exceed 4 miles over the normal errors shown in Figure III.5, which does not appear to add to the burden of reestablishing the barrier integrity. The communications function of the airplane barrier during the break in the NAVACOM chain can be handled from each side of the gap to the ground station and the gap bridged by the MHF backup. If for some reason the substitution is delayed, the gap may be minimized by stretching the line on either side until communications signals weaken.

For the example shown in Figure III.5, the greatest deterioration of the NAVACOM navigation accuracy occurs when the airplane nearest a shore station fails. In this event, the aircraft next to the casualty must receive its navigation information from the furthest station some 2200 miles away. The navigation information relayed over this distance will nearly double the dimensions of the largest error ellipse in Figure III.5.

If only the NAVACOM system fails the airplane will maintain station and continue its radar search, communicate with its MHF system, and navigate with its self-contained navigation system until relieved.

A failure in the radar has essentially the same effect as an airframe failure. There may be some value for the airplane to maintain station to preserve the NAVACOM chain but otherwise it should be relieved as soon as possible.

Spare radar and NAVACOM transmitters, receivers and power supplies carried in the airplane could reduce system failures to a very small number if the resultant increases in military load were considered acceptable.

Helicopter System Failures

Unairworthiness in the helicopter systems as in the case of the airplane systems will compromise the radar, communications and navigation of the barrier. If 16 minutes are allowed for climb to operations altitude and 10-15 minutes preparation before take-off, the time required to restore barrier integrity is of the order of one-half hour. The basing ship which acts as a navigation reference will not accumulate an appreciable error in this time. Pertinent information may be transmitted over the gap by MHF by the helicopters on either side of the gap. As in the case of the airplane the radar gap may be reduced by stretching the barrier towards the gap with high altitude coverage provided by the radar on the basing ship.

The consequence of a NAVACOM failure in the helicopter follows the same pattern as a similar failure in the airplane. For the example shown in Figure III.5, the navigation accuracy along the barrier suffers most with a NAVACOM failure in the helicopter nearest a land base. However, if the periods required for substitution are not too long, the basing ship of the troubled helicopter is capable of holding better navigation accuracy than that reported by the disabled NAVACOM chain and should be used as the navigation reference. The helicopter with the faulty NAVACOM equipment will maintain station, continuing its radar search, communicating with its backup MHF system and navigating by radar fixes on the basing ship, until relieved.

A failure in the radar has essentially the same effect as an airframe failure and a relief should be dispatched to restore the barrier integrity as soon as possible.

Airship System Failures

As in the case for helicopter and airplane systems, unairworthiness of the airship will create a breach in the barrier surveillance. Again, as in the airplane system, the breach can be filled by a closing-up process which will require a minimum time to restore normal operation. This process for the airship will require approximately 2 to 7 hours to complete, depending on the location of the faulty aircraft and the prevailing wind. A net result on the airship line will be a reduction in endurance due to the high speed shift to fill the gap, as in the case of the airplane.

Failures of the airship radar or NAVACOM systems will have the same results as in the helicopter and airplane. Unless on-board spares are provided, the airship must be relieved on station and returned to its land base.

RECAPITULATION

An examination of conventional and currently available airborne communications equipments indicated that these are inadequate to meet the communications performance level demanded by early warning. It was concluded, in view of the 1960 time period, that currently available techniques, but in a form new to airborne use, must be adapted by development to the specific requirements of the DEW systems under study.

An airborne microwave chain operating on a carrier frequency between 2000-3000 Mc appeared to be feasible. The system would use one kilowatt of power into the antenna feeds; and would employ directionally controlled antennas which would not pose unsurmountable installation problems on aircraft.

The microwave communications system is affected by the same phenomena that affect radar propagation. Hence, radar performance may be judged from the operation of the microwave system since the propagation of the communication chain is continually sampled.

The navigation potential of the microwave chain is exploited. Since the chain operates on radio line-of-sight, range and azimuth measurements can be made jointly with communications. The range and azimuth measurements may be achieved with the high level of accuracy required to maintain the barrier. Because of the dual use of the microwave chain the system is referred to as the NAVACOM (Navigation and Communications) system.

A secondary navigation system, in the form of electromagnetic doppler velocity and distance measuring equipment, is included. This equipment serves as a source of navigation information for base-to-station transits and also for emergency navigation should the NAVACOM System be disrupted.

The effects of airframe, radar, and NAVACOM system failures are examined individually and in combination for their effect on the early warning system. The effect of an airframe failure requires the maximum of time and effort to reestablish the barrier integrity. The estimated times to restore the barrier for the three aircraft systems are:

1. One hour for the airplane system.
2. One-half hour for the helicopter system.
3. Two to seven hours for the airship system.

The conclusions of this study indicate that the spacings based on radar performance (Chapter II) are not compromised by the communication and navigation problems, provided the degree of effort already manifested in the case of radar is applied to the communications and navigation systems.

CHAPTER IV

TACTICAL MODELS

GENERAL CONSIDERATIONS

Choice of the tactical model for warning barriers depends upon many factors, such as geography, the aircraft type, and the mission to be accomplished. This chapter is concerned with the basic model, with the variations from the basic model which are used for each of the aircraft types, and with the formulas developed for determining the number of aircraft required to maintain a round-the-clock barrier.

There are as many possible barrier patterns as there are people who have examined the barrier problem. It is impossible to design a single barrier pattern which can be applied to all of the aircraft types discussed in this study because of the varied characteristics of the three vehicles considered. The airplane has the advantage of a wide range of possible values for speed, endurance and altitude. This permits an almost unlimited number of design point combinations. In addition, the design point airplane has a considerable amount of operational flexibility. The helicopter is limited by its low speed and short endurance. Its principal use is in a hover mission. The airship can utilize its very long endurance and its load carrying capacity but is altitude limited. With these characteristics considered, the range of selection is limited to those models which appear best for the aircraft under analysis.

AIRPLANE SYSTEM TACTICAL MODELS

The barrier pattern generally visualized for the airplane is the double "pipe line", or continuous barrier. Early in the study of this problem, however, it became apparent that other patterns offered attractive savings in force requirements.

Methods of Employment

The following pages illustrate graphically four methods of employing airplanes in barrier patterns. Both double and single lines are included. From these basic methods of employment many variations in pattern can be designed according to the requirements of the situation.

Double Line Barriers

The pipe line is a simple continuous barrier in which the airplanes fly round trips between two bases. The spacing, S, is such that overlapping radar coverage is provided, and search is continously conducted on both the going and returning legs. Figure IV.1a illustrates the wide, double-line pattern formed by this type of barrier design. This type of barrier is especially adapted to DEW & C operations because of its depth of coverage.

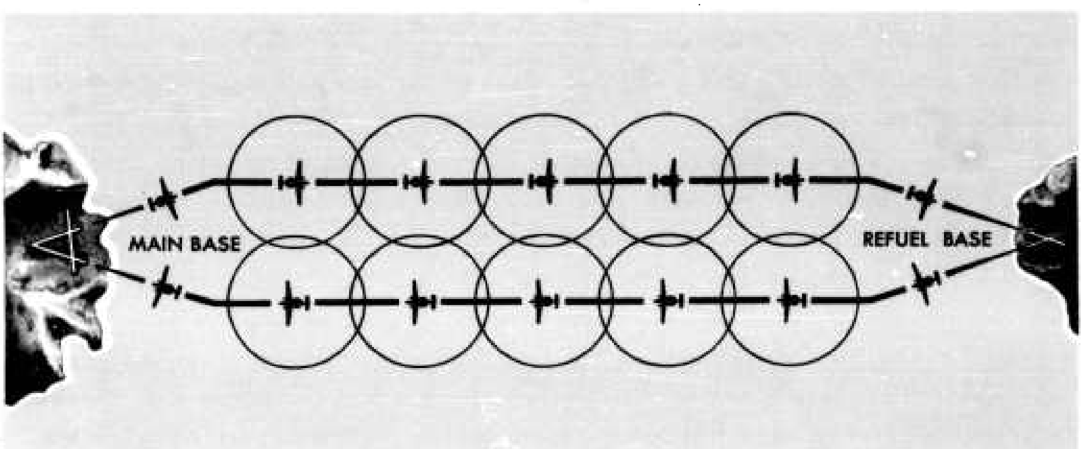


FIGURE IV.1-a: THE PIPELINE METHOD

Single Line Barriers

Three methods of employment are used in single-line barriers. These are designated as bump, shift and oscillating. The concept of the bump method is the outgrowth of conferences with personnel of CNO. The oscillating method originated in the office of the Operations Evaluation Group. The techniques involved in each of these operations are described below.

1. The Bump Method

In this method the airplane positions are established at spacing S (in this example, 400 miles); and a circular orbit is flown at each

station within a few miles of a fixed reference point, P. The bump process is started by the outcoming airplane, which relieves No. 1 station. Airplane A then moves on to bump, or relieve, No. 2 position, which in turn bumps No. 3. This procedure continues until Airplane E, in Station No. 5 has been relieved. Airplane E then returns to base. Figure IV.1b illustrates this method.

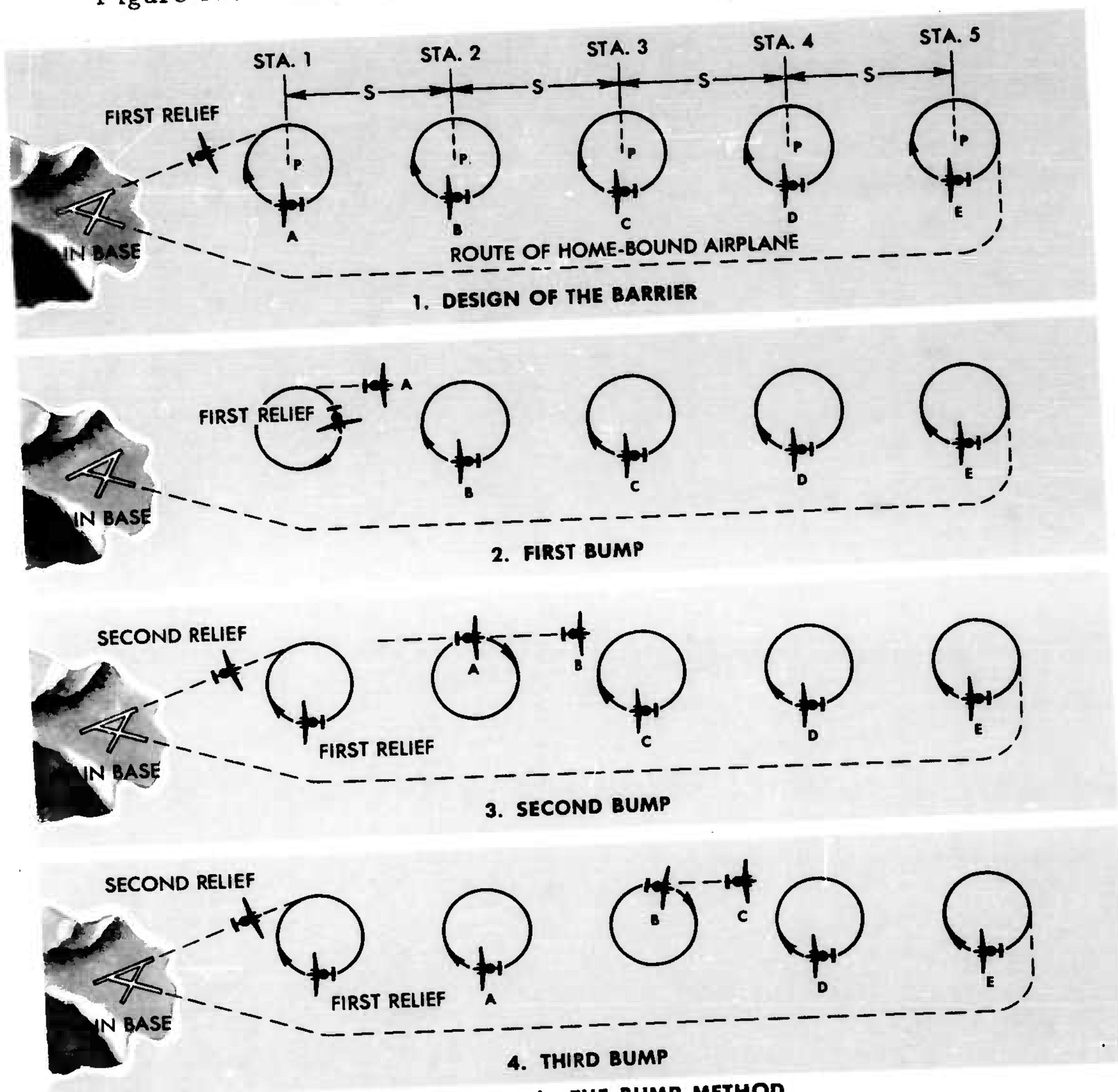
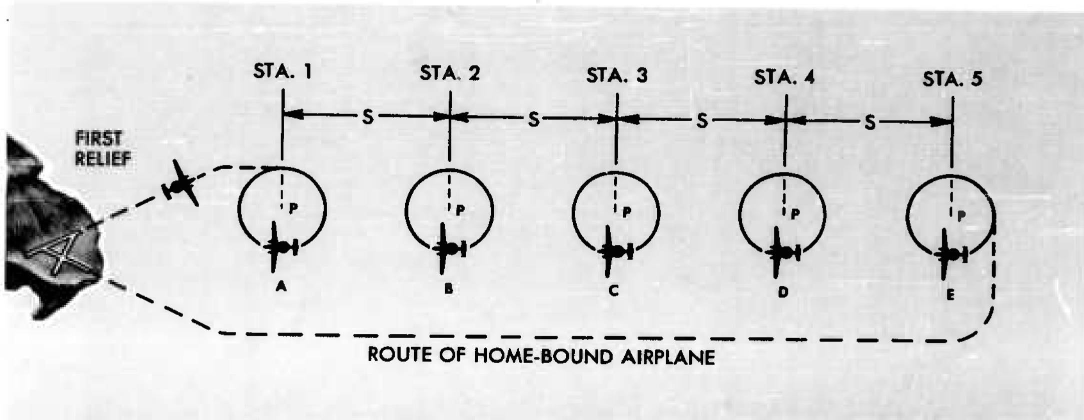


FIGURE IV.1-b: THE BUMP METHOD

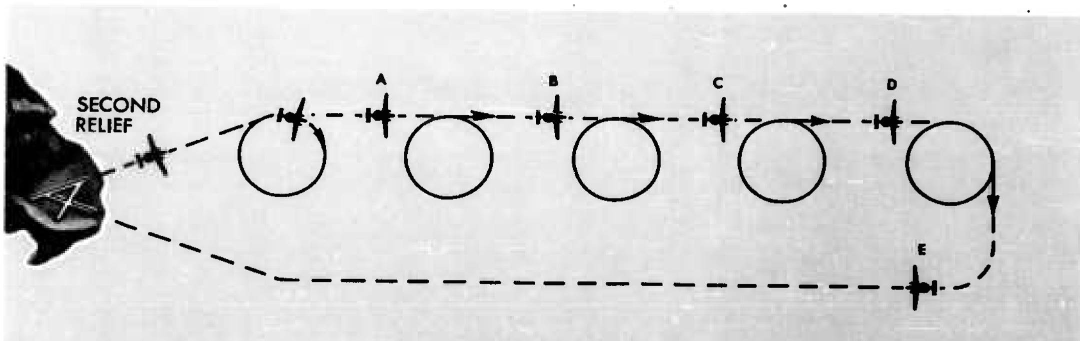
Radar search is continuously conducted by all airplanes, while on station, while changing position, and while returning home. It should be noted that any airplane, during the station change or homeward bound, provides redundant radar coverage and is not depended upon to maintain the integrity of the line.

2. The Shift Method

The shift method resembles the bump with the notable exception that when the relief airplane reaches No. 1 station, all airplanes move one position forward in the barrier line. Airplane E, in No. 5 station is relieved for return to base. Figure IV.1c illustrates the first shift; all succeeding shifts are accomplished in the same manner. Radar search



1. DESIGN OF THE BARRIER



2. SHIFT TECHNIQUE

FIGURE IV.1-c: THE SHIFT METHOD

is conducted both while orbiting and while changing stations. The airplane leaving No. 5 station continues to search during its return to base, thus providing redundant radar coverage.

3. The Oscillating Method

The oscillating method, illustrated in Figure IV.1d, was developed to provide a continuous flow of airplanes into a single-line barrier without search redundancy. Two bases are required for the operation. Airplanes leave Base X and fly directly toward Base Y, at spacing S. When the first airplane from Base X arrives within radar range of Base Y, all units from Base X reverse course and proceed toward home. At the same time, in order to maintain the required spacing, airplanes

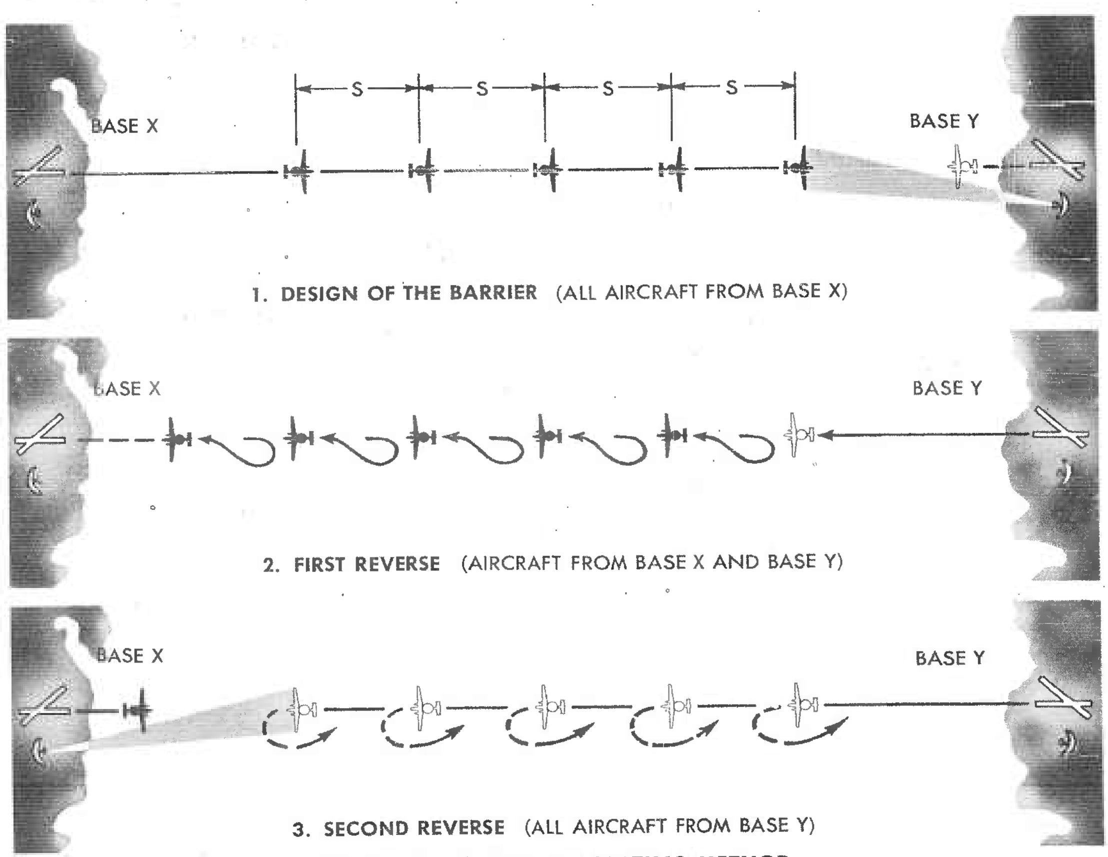


FIGURE IV.1-d: THE OSCILLATING METHOD

from Base Y take their places in line, flying toward Base X. As before, when the first airplane from Base Y is within radar range of Base X, the entire line reverses and the procedure is repeated. It is essentially a push-pull operation. Radar search is conducted continuously by all airplanes in the barrier.

Figure IV.2 shows the effect on force requirements of using different methods of employment as a function of aircraft range for an early warning barrier of given length and aircraft spacing. It is seen that the pipe line requires the greatest number of aircraft and the oscillating barrier the least.

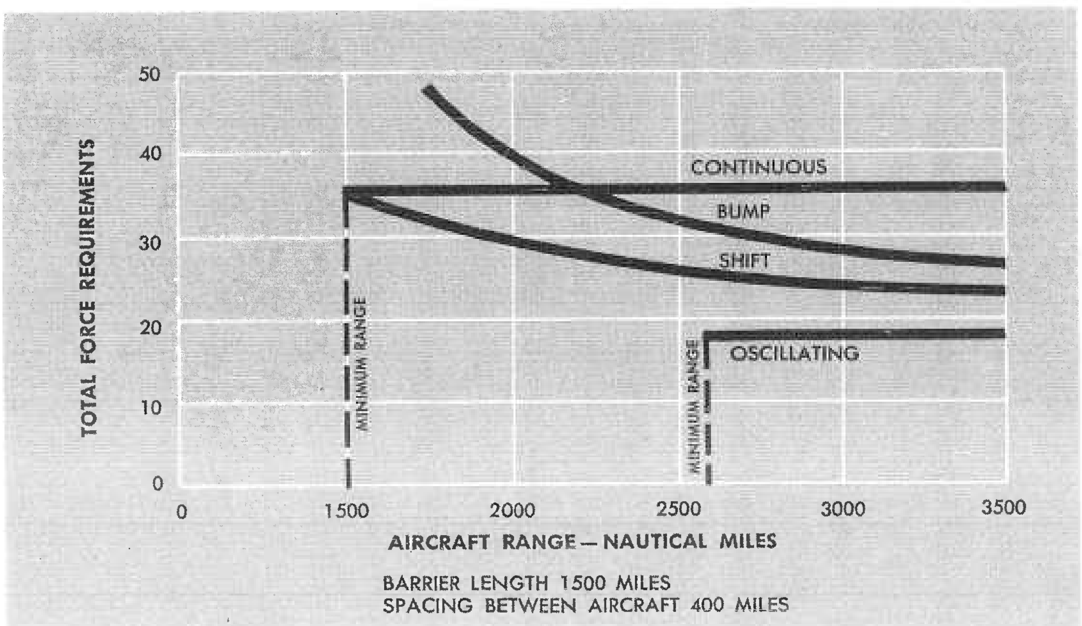


FIGURE IV.2—EARLY WARNING BARRIER FORCE REQUIREMENTS

Barrier Patterns

Representative patterns selected from the many possible basic designs are shown in Figure IV.3. Combinations of one-and two-base, single-and double-line, and one-half and full-length, patterns are examined. The odd-numbered patterns are double lines and the even numbered are single lines.

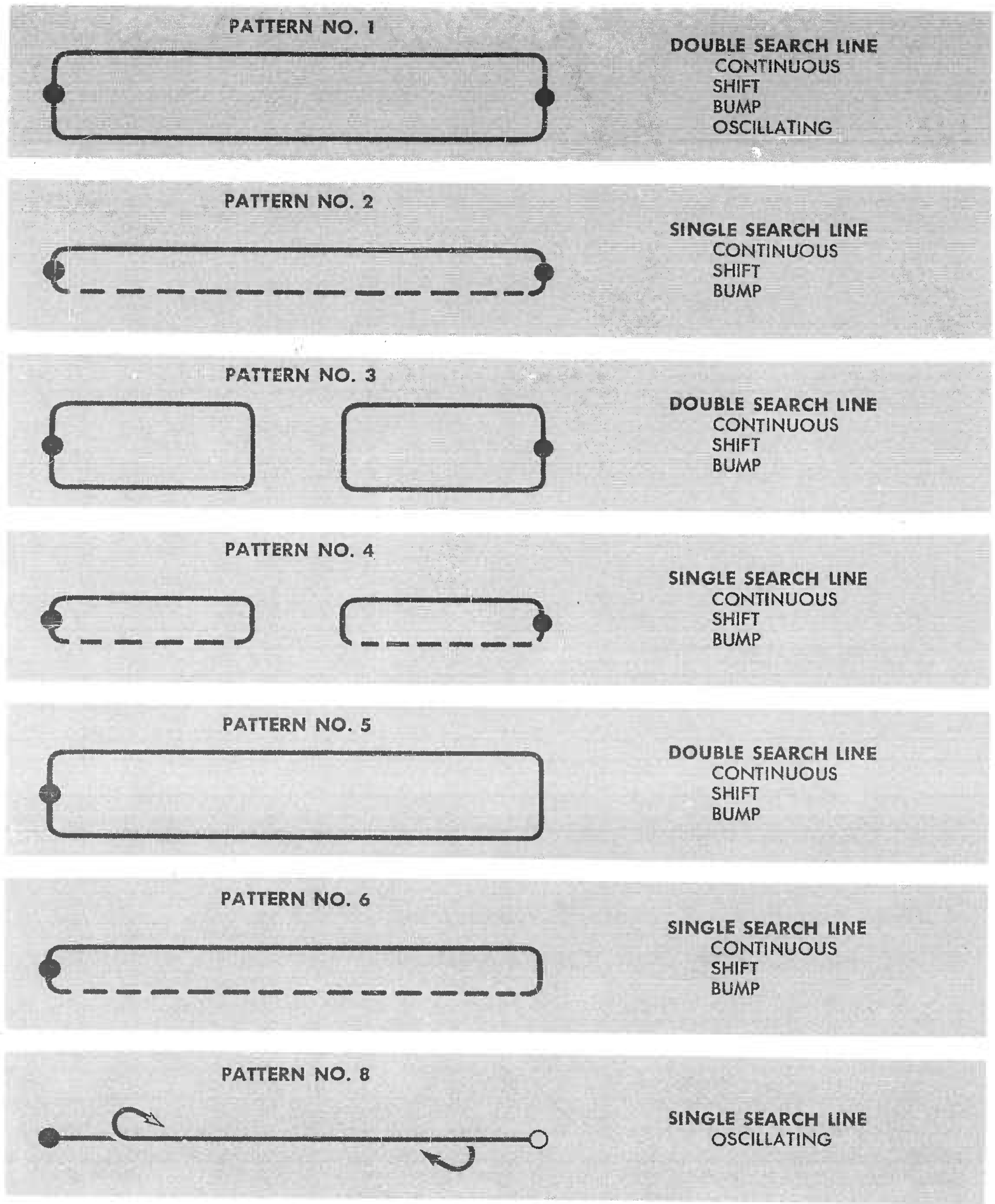


FIGURE IV.3—BASIC BARRIER PATTERNS

It should be noted at this point that certain of the various methods of employment are not applicable to all of the basic patterns. Figures IV.1a through d classify certain basic methods of employment. Comparison with Figure IV.3 discloses the fact that patterns are merely variations within the methods of employment. It would be a simple matter to design a vast number of these patterns, but no more useful end would be gained by using any more than the group shown in Figure IV.3, which are representative of the range of patterns.

Barrier Lengths

Examination of the geographic areas in which the barriers might be flown indicates the probable lengths of the barriers. The longest barrier that the Navy might be called upon to fly is in the Pacific, the maximum distance between bases in the Hawaiian Islands and Alaska being approximately 2400 miles. The shortest over-water barriers contemplated are approximately 1000 to 1500 miles in length. Consequently, for all calculations, four typical barrier lengths are used: 1000, 1500, 2000 and 2500 miles.

Bases

The two base configurations used in this report are:

Class A - A base capable of complete logistic support of aircraft, and from which barrier operations are conducted.

Class B - An auxiliary staging base for landing, refueling, and emergency repairs.

The geographic location of a base affects its cost to some degree. The terms used to identify the various bases are:

Continental - A U.S. Base, where costs are normal.

Overseas - An overseas base, where operating conditions lie within average bounds, such as Port Lyautey, Azores, or other location where costs are not excessive.

Northern - An overseas base located in northern areas. This base would be more costly than a standard overseas base, because of the extreme operating conditions encountered in high latitudes.

Since the barrier operations discussed in this study are limited to the seaward approaches to the continent, they are therefore oriented generally north-to-south. Four combinations of base type and location are considered. These are:

1. Northern B and an overseas A
2. An overseas A
3. Two continental A's
4. Northern A and an overseas A.

Number of Aircraft Required

The basic equation for the number of aircraft required to maintain a barrier is:

$$N = \phi \frac{T_m}{I}$$

where:

N = Total number of aircraft required to maintain the barrier.

ϕ = A utilization factor equal to the ratio of the number of hours flown in barrier operation to the number of hours per month. This factor is discussed in detail in Reference 27, and in each of the aircraft chapters.

T_m = The total mission flying time.

I = The take-off interval between aircraft.

The use of this general equation generates a set of specific equations for determination of N for the various conditions of employment and barrier pattern. The equations are summarized for fixed-wing airplanes in Figure IV.4. Note that for double line barriers the aircraft spacing, S, is the same for both lateral and longitudinal directions.

Final Models

If all the lengths, base configurations, barrier types and methods of employment are considered 352 possible combinations result. Analysis of the equations of Figure IV.4 indicates that certain methods of employment are unproductive when used in certain barrier patterns. This analysis of the equations indicates:

1. The bump method always requires more airplanes of equivalent range than the shift.

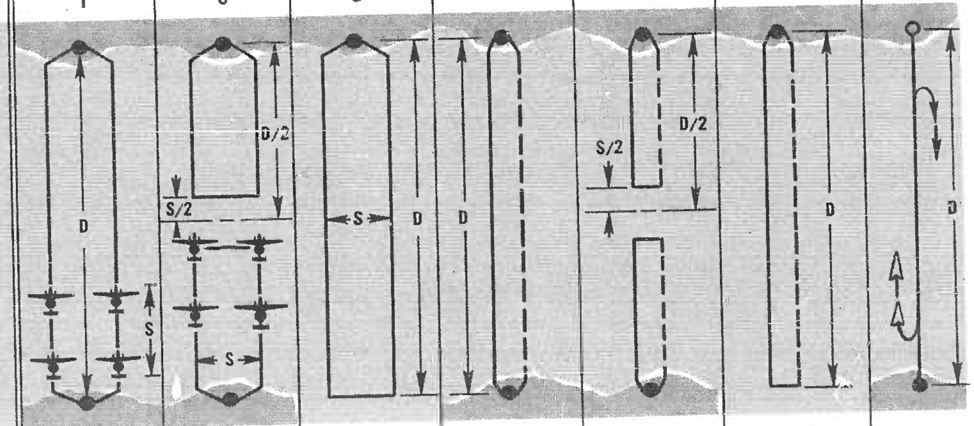
2. The oscillating method is only usable with barrier patterns 1 and 8. However, for barrier 1, the range requirement dictates a large airplane with no saving in force requirement and is dropped from further consideration.

3. For the double-line barriers the pipe line, or continuous, method always requires fewer airplanes than the bump or shift methods.

4. Barrier pattern 3 offers no advantage over barrier pattern 1 since it requires the same number of airplanes with the same range capability, and, in general, the base costs are higher. This pattern is dropped from further consideration.

DETERMINATION OF TOTAL FORCE REQUIREMENTS

BARRIER PATTERN — BASE TYPE



BARRIER NO.	1	3	5	2	4	6	8
CONTINUOUS	$2\phi \frac{(D+1)}{S}$	$2\phi \frac{(D+1)}{S}$	$2\phi \frac{(D+1)}{S}$	$2\phi \frac{D}{S}$	$2\phi \frac{D}{S}$	$2\phi \frac{D}{S}$	—
SHIFT	$\frac{2\phi \frac{(D+1)}{S}}{1-\frac{S}{R}}$	$\frac{2\phi \frac{(D+1)}{S}}{1-\frac{S}{R}}$	$\frac{2\phi \frac{(D+1)}{S}}{1-\frac{S}{R}}$	$\phi \frac{D}{S} \frac{R+D}{R-S}$	$\phi \frac{D}{S} \frac{1}{1-\frac{D}{2R}}$	$\phi \frac{D}{S} \frac{1}{1-\frac{S+D}{R}}$	—
BUMP	$\frac{2\phi \frac{D+1}{S}}{1-\frac{D+S}{R}}$	$\frac{2\phi \frac{D+1}{S}}{1-\frac{D+S}{R}}$	$\frac{2\phi \frac{D+1}{S}}{1-\frac{2(D-S)}{R}}$	$\phi \frac{D}{S} \frac{R+D}{R-D}$	$\frac{\phi \frac{D}{S}}{1-\frac{D-S}{R}}$	$\frac{\phi \frac{D}{S}}{1-\frac{2D}{R}}$	—
OSCILLATING	$2\phi \frac{(D+1)}{S}$	—	—	—	—	—	$\phi \frac{D}{S}$

A — MAJOR BASE
B — SECONDARY BASE
D — DISTANCE OVER WHICH PROTECTION IS PROVIDED
S — SPACING BETWEEN AIRCRAFT
R — OPERATIONAL RANGE OF AIRCRAFT

FIGURE IV.4

The base configurations are matched to the barrier patterns. Barriers 4 and 8 require the two class A base configurations. Barriers 5 and 6 require the single class A base, and barriers 1 and 2 require class A-class B bases in combination.

A DEW & C barrier must have considerable depth in order to allow time to accomplish the functions of detection, tracking, identification, decision and bringing weapons to bear. The DEW barriers can accomplish their warning mission with less depth. For these reasons the double line barriers are used for DEW & C and the single lines are used for DEW. For the DEW & C barriers the two different spacings considered are dictated by the capabilities of the height finding systems. For the first, it is assumed that some modification to the UHF radar system will permit the system to conduct height finding to a range which is a fraction of the search range achievable. In the second situation, the airplane is equipped with an X-band height finder as typified by the AN/APS-45 radar. In this case, the reliable height finder range, rather than the search range, determines the spacing.

As a result of these considerations, the number of tactical model variations is reduced from 352 to 32.

Figure IV.5 shows the airplane tactical model combinations used in this study.

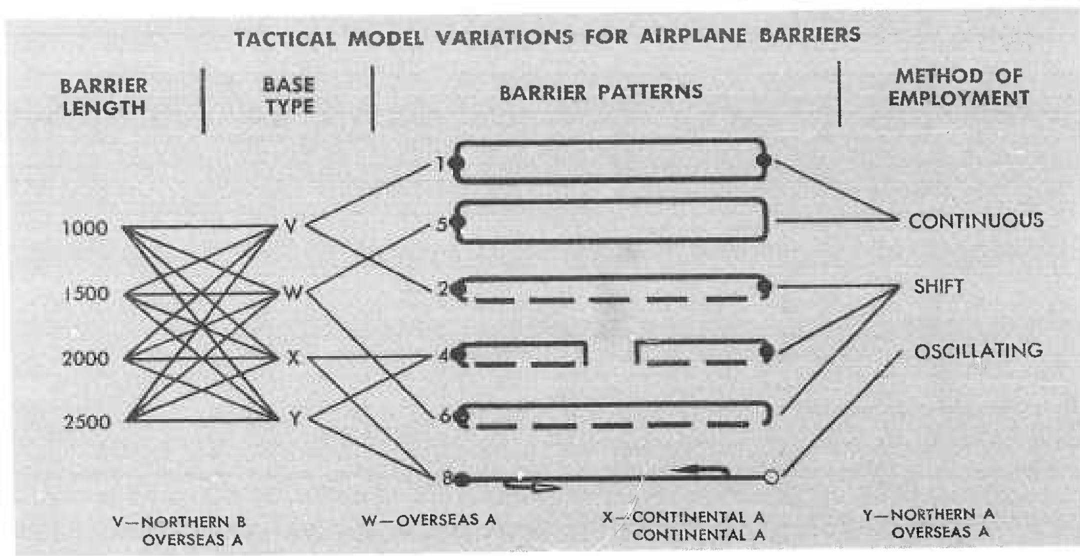


FIGURE IV.5

HELICOPTER SYSTEM TACTICAL MODELS

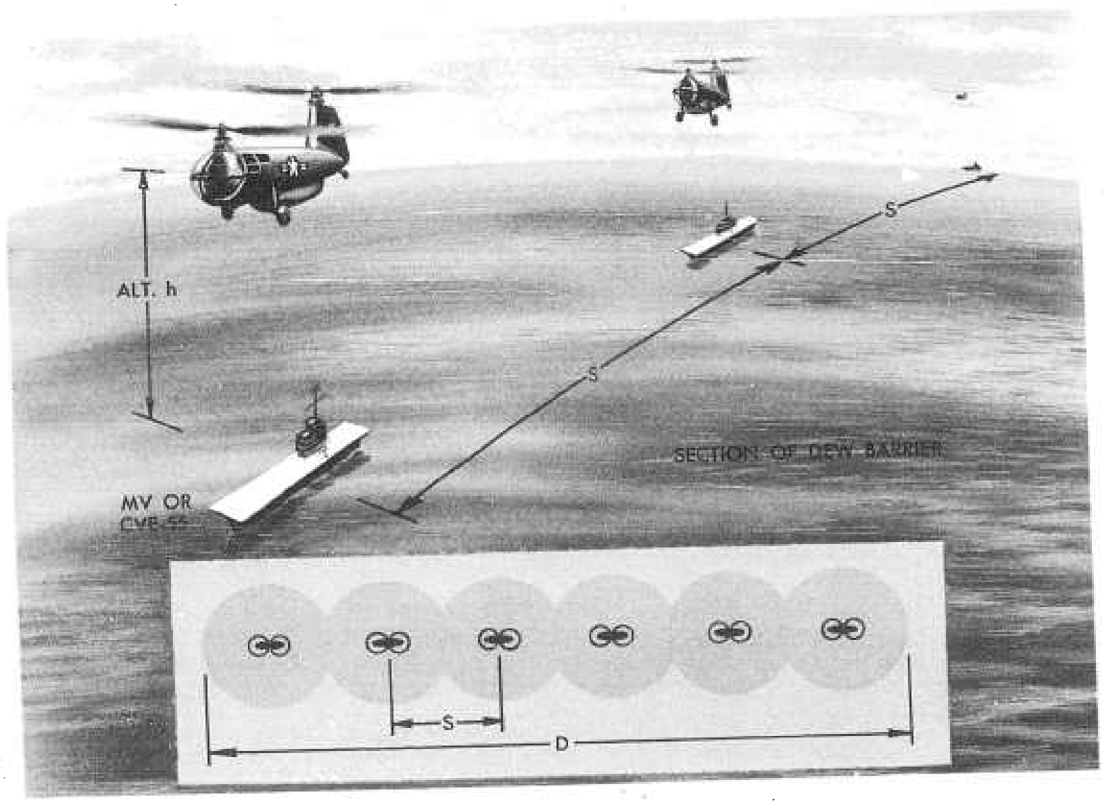
Method of Employment

If the helicopter is required to transit, it is no longer competitive with other airborne systems because of its low speed and short endurance. The only method of employment considered for the helicopter is that of hovering or orbiting in the vicinity of the floating base from which it operates.

Barrier Lengths and Patterns

The barrier lengths considered are the same as those for the airplane; that is, 1000, 1500, 2000 and 2500 miles.

For the DEW barrier, a single line is used. The helicopter rises to altitude, hovers or orbits to the limit of its endurance in the vicinity of the



DEW BARRIER
(RADAR COVERAGE ILLUSTRATED BY CIRCLES. HELICOPTERS SPACED S MILES APART)
FIGURE IV.6a—DEW BARRIERS

station ship, is relieved on station and returns to the ship. The spacing between the helicopters, and necessarily the ships, is dictated by the radar characteristics, as shown in Figure IV.6a.

The DEW & C barrier is a double-line barrier and is spaced according to the height finder radar capability. As in the airplane tactical models different spacings are considered. Figure IV.6b illustrates this model.

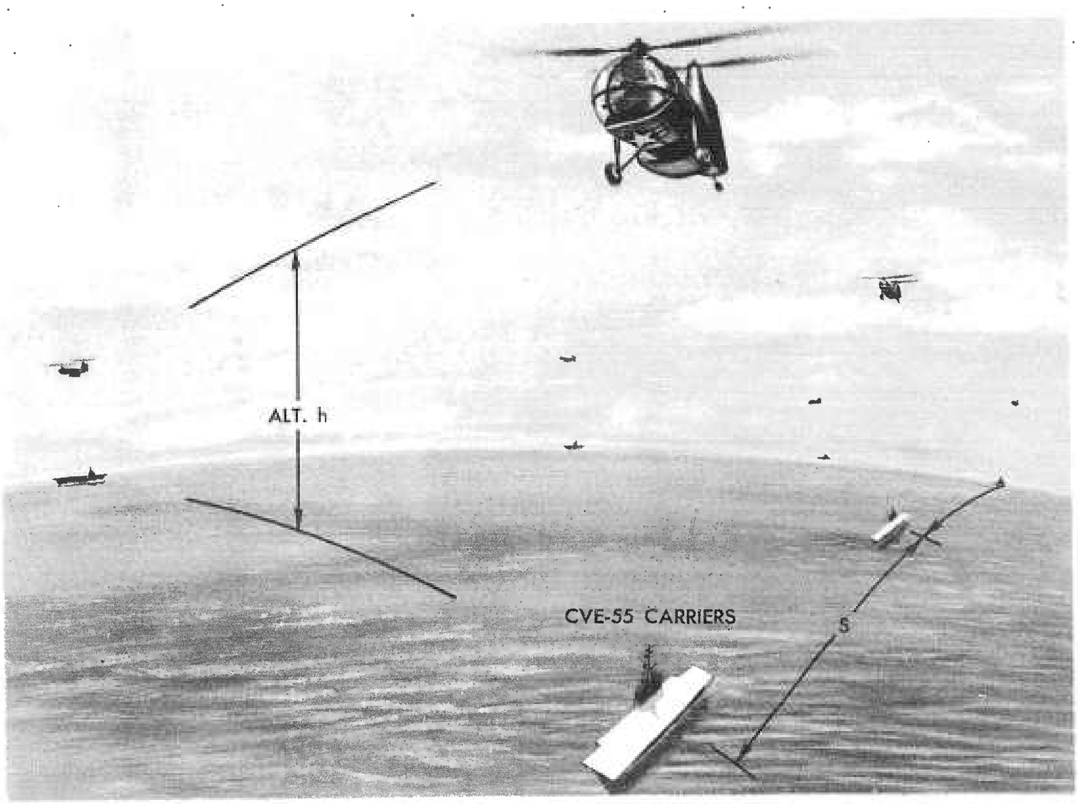


FIGURE IV.6b—DEW & C BARRIERS

Ship Bases

Two types of ship bases, CVE's and converted merchant vessels, are used in this analysis. The converted merchant vessel is introduced in an effort to provide a lower cost system. It is assumed that these vessels are Liberty types, and that they provide a launching and stowage area from the bridge structure forward.

The carrier type is the CVE-55 class with a minimum crew. These are standard CVE's with only slight changes to carry out the function of station ships.

In general, the size of the helicopters required for DEW & C dictates that only the CVE class is capable of handling them. Consequently, both the CVE and converted MV are considered for the DEW barriers but only the CVE is used in the DEW & C barriers.

Helicopter Force Requirements

The basic equation for the number of helicopters required is the same as that for airplanes:

$$N = \emptyset \frac{T_m}{I}$$

Using the basic equation, the formula for the number of helicopters required is obtained and is:

$$N = \emptyset \frac{D}{S} \left(1 + \frac{T_{cd}}{T_s}\right)$$

where:

D = Barrier length

S = Spacing between stations

T_{cd} = Time to climb and descend

T_s = Time on-station or endurance

Final Models

The final models are easily selected because of the simplicity of this system. It is assumed that the helicopter heavy maintenance bases are in the United States and no overseas bases are considered.

It is shown in Chapter VI that the cost of the helicopter system is a direct function of the barrier length. Consequently, a length of 1000 miles is used for all calculations. The models are shown in Figure IV.7.

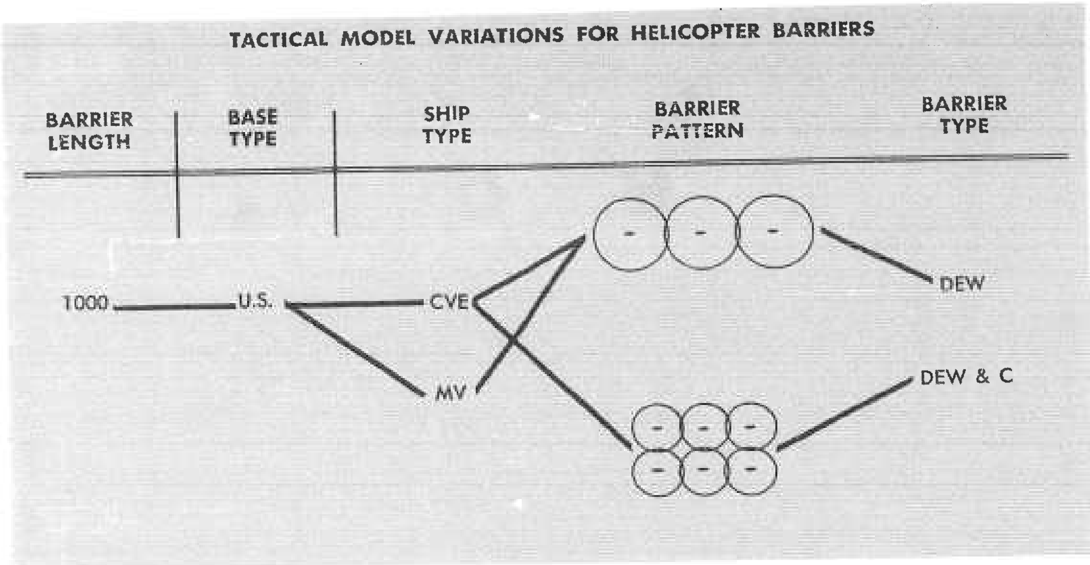


FIGURE IV.7

AIRSHIP SYSTEM TACTICAL MODELS

Methods of Employment

In the early phases of this study, it appeared that airships could be employed using the same methods as for the airplane. A closer examination of the problem showed the use of pipe line, shift, and bump methods of employment to be somewhat impractical.

The Goodyear parametric analysis considers two different methods of employment — continuous and hover. Transit at altitude is more expensive because the airship encounters higher average headwinds. In addition, any line in which moving airships attempt to maintain exact positions relative to each other appears very difficult to achieve. A separate analysis indicates that the missions involving other than hover techniques are always at least as costly as the hover mission and in general are more expensive. The decision was made to consider only barriers using the hover method of employment.

In this technique, each station in the barrier is maintained independently. The airship leaves its base, proceeds at sea level to its assigned station, rises to altitude, hovers for its endurance period, is relieved on-station, descends to sea level and returns to base. The airship is designed for this

generalized flight pattern. However, in actual operations, it would obviously take advantage of weather conditions to determine best transit altitude.

Barrier Patterns and Lengths

Six barrier patterns are used. These are designated as airship Barriers 1 through 6, and are shown in Figure IV.8. In Barriers 1 and 2 the base is located abreast of the barrier. In Barriers 3 and 4 the bases are located at the ends of the line. Barriers 5 and 6 are modifications of Barriers 3 and 4 in that only one base is involved at the end of the line.

Barriers 1 and 2 are calculated for a length of 1000 miles and the cost of other barriers of this type can be obtained by the simple ratio of lengths. Barriers 3 and 4 use lengths of 500, 1000 and 1500 miles, while Barriers 5 and 6 use lengths of 1000, 2000 and 3000 miles. The analysis is such that simple interpolation can be used to determine results for barriers of other lengths.

Base Configurations

The airships in Barriers 1 and 2 operate from a continental base. Those in Barriers 3 and 4 operate from two overseas bases. The base for Barriers 5 and 6 is either a continental or an overseas base. Barriers 3 and 4 resemble those used in the airplane system in that one of the overseas bases is considered to be located in a northern area.

Airship Force Requirements

The basic equation for the number of airships required for a barrier is the same as for the other aircraft.

$$N = \phi \frac{T_m}{I}$$

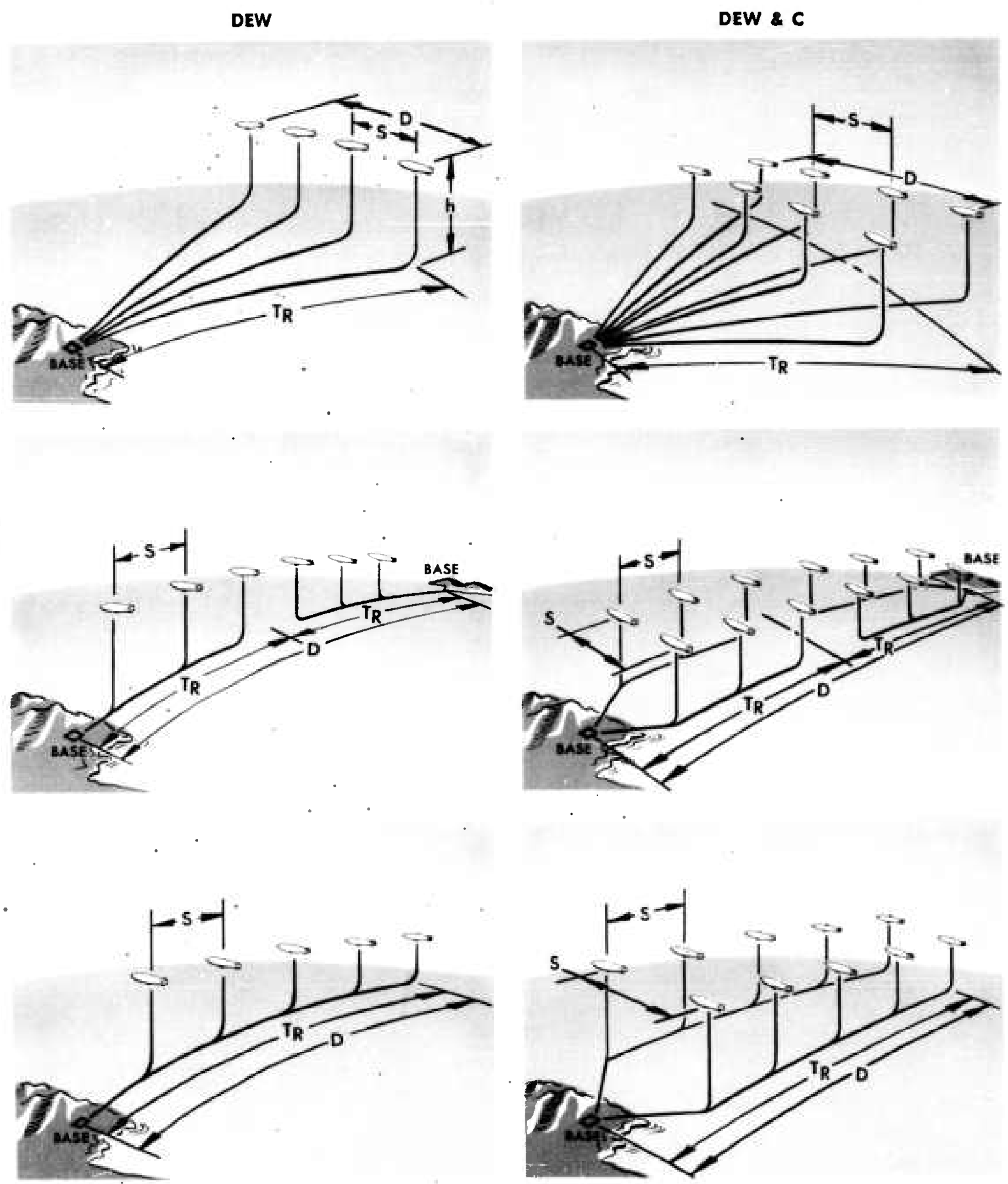
For Barriers 1 and 2, it is assumed that the transit radius is constant and with this assumption the equation for force requirements is quite simple:

$$N = \phi \frac{D}{S}\left(\frac{T_m}{T_s}\right)$$

where

T_m = Total mission time

T_s = Time on-station



D = BARRIER LENGTH T_R = DESIGN TRANSIT RADIUS h = ALTITUDE

FIGURE IV.8—AIRSHIP BARRIER PATTERNS

For the remaining barriers each station requires a different number of airships to maintain it since the transit time to each station differs. The general equation for determining N is:

$$N = \emptyset \frac{D}{S} \left[\frac{T_{m_1}}{T_{s_1}} + \frac{T_{m_2}}{T_{s_2}} + \dots + \frac{T_{m_n}}{T_{s_n}} \right]$$

Final Models

Here again the types of barrier required for the DEW and the DEW & C missions are different. For the DEW & C barrier, depth remains important and necessary. In order to obtain this depth, two DEW barriers are employed. In the case of the airship, it is shown in Chapter VII that the addition of small increments of military load has negligible effects on system cost. Consequently, the addition of a larger radar antenna to permit height finding to the limit of search range spacing is feasible and with no detectable increase in system cost.

The models used are shown in Figure IV.9.

TACTICAL MODEL VARIATIONS FOR AIRSHIP BARRIERS

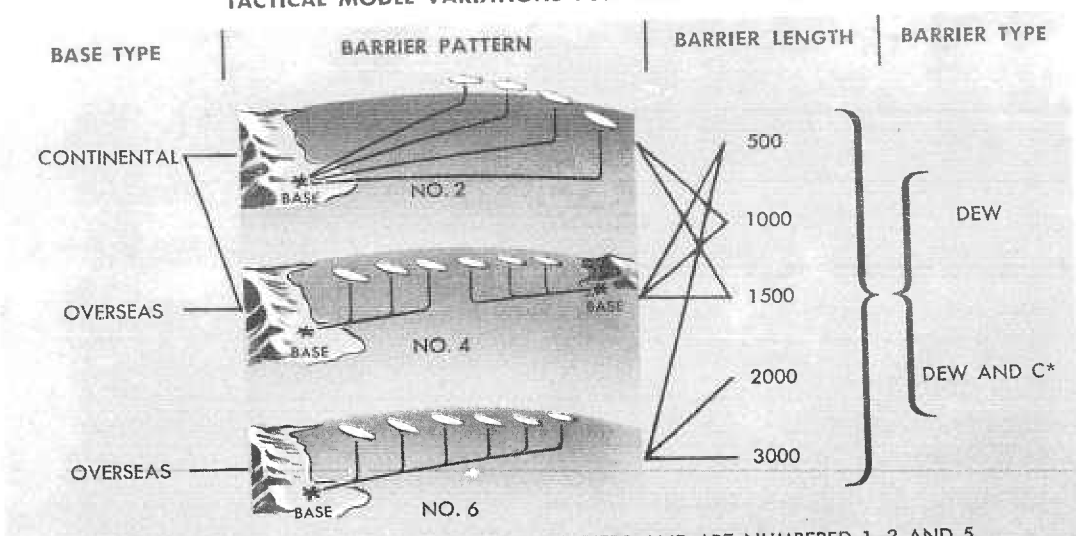
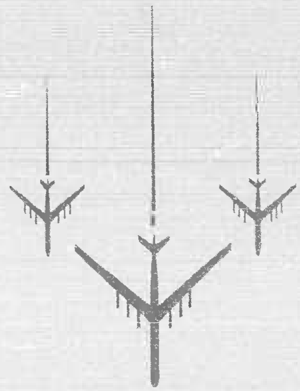
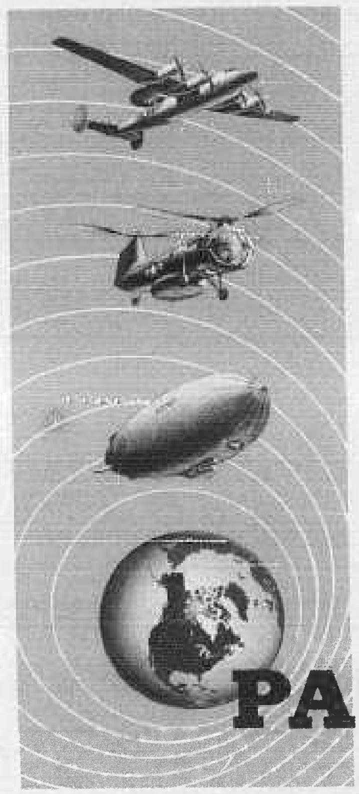


FIGURE IV.9





PART III

- OPTIMUM AIRPLANE SYSTEMS
- OPTIMUM HELICOPTER SYSTEMS
- OPTIMUM AIRSHIP SYSTEMS

INDEX TO PART III

CHAPTER V

SELECTION OF OPTIMUM AIRPLANE SYSTEMS

The airplane is the first of three vehicle types examined in this report for the accomplishment of the DEW and DEW & C tasks for the conditions outlined in Chapter I. The main components which combine to form the DEW system are the airplane, radar, bases and personnel. In addition to these system components there are certain associated techniques and operations, among which are barrier patterns, base configurations, and methods of employment.

There is, however, only one best system, and this may be defined as the group of associated components and operational techniques which can accomplish the DEW or DEW & C missions most effectively and at the least cost. Simultaneously, this accurately defines the measure of effectiveness used in the present analysis and expressed, simply, as the level of detection obtained in return for a certain investment, or cost per year. The reasoning processes through which the measure was developed are discussed in some detail in Chapter I.

The principal factors which enter into the measure of effectiveness are:

[AIRPLANE BARRIER SYSTEM COST] = [AIRPLANE COST] + [FUEL COST] + [MAINTENANCE COST] + [MILITARY LOAD COST] + [CREW COST] + [BASE COST]

To obtain this barrier system cost, an airplane parametric analysis is set up to systematically vary the parameters which affect the system components. In order to compute design point airplanes, the interaction of the components, techniques and operations is examined in detail.

THE PARAMETRIC ANALYSIS

The purpose of the analysis is to select certain combinations which result in the least system cost. Data on the techniques involved in the parametric analysis and the equations used to develop the design point airplanes will be found in Reference 27. Figure V.1 shows diagrammatically the inputs used

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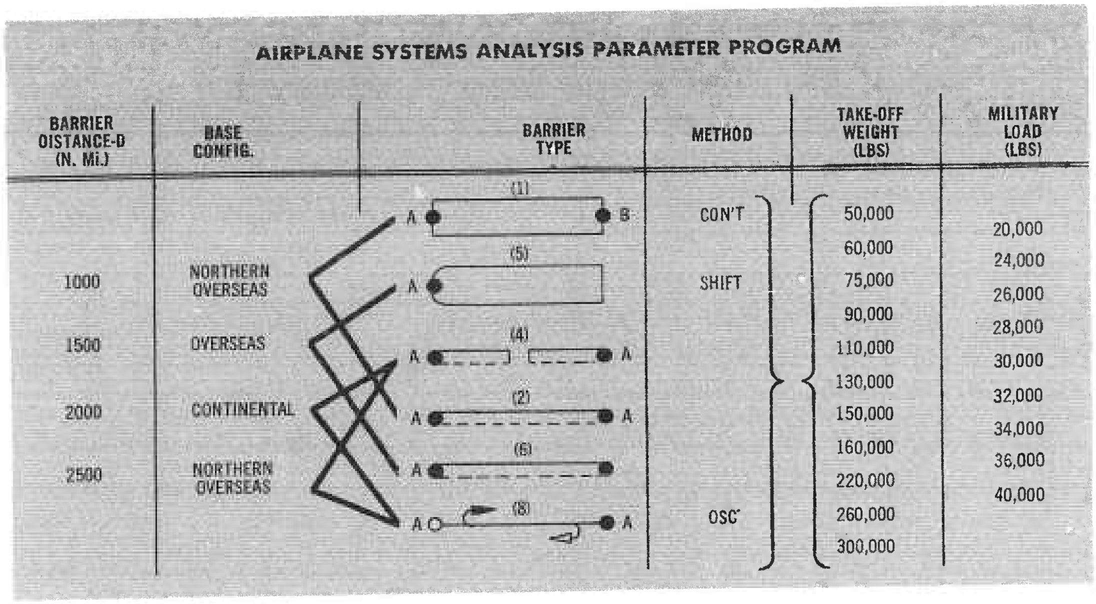
27. R. W. Allen. *Early Warning Airplane Parametric Analysis.* Lockheed Memorandum Report 7090. Military Operations Research Division, Lockheed Aircraft Corporation, 1 July 1955. (CONFIDENTIAL)



RADOME SIZE (FT)	RADAR PERFORMANCE LEVEL	OPERATOR FACTOR P_0	BARRIER SPACING S (N. MI.)	ALTITUDE (FT)	VELOCITY (KTS)	WING LOADING LBS/SQ FT	ASPECT RATIO	POWER PLANT
	2	.05	252	15,000				
(1) 4.8 x 20 (UHF)		.1	281	15,000				
	1	.05	349	20,000	150			
		.1	360	20,000		30		
	SW-1	.05	412	35,000				
(2) 6.3 x 31.5 (UHF)		.1	452	35,000				
	2	.05	346	29,000	175		14	
		.1	382	29,000		40		TURBO-PROP
	1	.05	475	35,000				
(3) 7.5 x 37.5 (UHF)		.1	490	35,000	200		12	
	2	.05	412	35,000		50		
		.1	452	35,000				
	1	.1	525	50,000	225			
(4) 7.5 x 37.5 (S)		.05	316	22,000				
	2	.1	348	22,000				
		.05	441	32,000				
	1	.1	460	32,000				
(5) 10 x 50 (UHF)		.05	436	35,000				
	2	.1	525	50,000				

FIGURE V.1

in the analysis. As noted in Chapter IV, the bump method is discarded.

Airplane Characteristics

A few of the parameters which directly apply to the airplane are discussed more fully in order to give a clearer understanding of the selection of the analysis inputs.

Performance

The results of a preliminary analysis and the performance requirements for DEW airplanes indicate that the low wing loading and the high aspect ratios should be used. This is because the DEW airplane must be capable of flying at a relatively low speed and must carry a specified military load with the lowest possible gross weight.

Power Plant

A turboprop power plant is selected because previous analysis has shown that, within the range of design points under consideration, this type yields as low an airplane system cost as the reciprocating type powered airplane, if not lower. Furthermore, the best system performance, radar and tactical, occurs at altitudes of 20,000 feet and above. This fact alone practically rules out the use of the reciprocating engine. The turbojet engine is not included parametrically because its specific fuel consumption is always greater than that of the turboprop engine at all altitudes considered in this analysis. Although the turbojet engine has a lower weight-to-thrust ratio than the turboprop engine, it is not a significant amount at the lower velocities.

Crew Requirements

As airplane endurance increases, larger crews are required. The crew schedule selected is shown in Figure V.2.

The crew for the DEW airplane is composed of pilot, co-pilot, navigator, CIC officer, engineer, radioman, radarman, and electronic technician. The DEW & C airplane includes additional radar men, height finder operators and an AI operator for those airplanes containing offense or defense capability.

Military Load

The military load for the DEW airplane consists of the crew, crew equipment, radome weight, electronic equipment associated with the radar and communications, power supply, galley, and furnishings. The DEW & C

military load includes the same items as for the DEW airplane with height finder equipment and a control computer added.

CREW SIZE AND MILITARY LOAD SCHEDULE

	0 TO 18 HOURS ENDURANCE			18+ HOURS ENDURANCE		
	MILITARY LOAD			MILITARY LOAD		
RADOME SIZE	DEW	DEW & C MINIMUM	DEW & C MAXIMUM	DEW	DEW & C MINIMUM	DEW & C MAXIMUM
(1) 4.8 x 20	20,000	24,000	26,000	24,000	28,000	30,000
(2) 6.3 x 31.5	24,000	28,000	30,000	28,000	32,000	34,000
(3) 7.5 x 37.5	26,000	30,000	32,000	30,000	34,000	36,000
(4) 10 x 50	32,000	36,000	40,000	36,000	37,000	42,000
	CREW SIZE			CREW SIZE		
PILOT CO-PILOT NAVIGATOR	4	4	4	9	9	9
CIC OFFICER	2	3	4	3	3	5
ENGINEER	2	2	2	3	3	3
RADIOMAN	2	1	1	3	3	3
RADARMAN	3	5	5	6	9	9
ELECTRONIC TECH	1	1	1	2	2	2
HEIGHT FINDER	–	2	2	–	3	3
TOTAL CREW	14	18	19	26	32	34

FIGURE V.2

These military loads are identified by different endurance levels, missions, radome sizes, and in the case of DEW & C, by assuming a maximum and minimum control capability. The maximum control capability is achieved by installing two control computers in the airplane. The values of military load for the various combinations are shown in Figure V.2.

The DEW & C with defense includes the same military load items as the DEW & C, but with the additional weight of missiles and AI gear. For the DEW airplane with burst speed capability, the military load items remain the same as in the DEW airplane.

Radomes

The various radome sizes used in the analysis are listed in Figure V.2 and range from twenty feet to fifty feet in diameter. Drag and stability requirements dictate the use of a lenticular shape with a fineness ratio of 5:1. The radome is mounted on a pylon located on top of the fuselage aft of the wing. The top-mounted rotating radome as against other possible types is selected because of the improved drag and stability characteristics. DEW airplane altitudes are chosen on the basis of the radar performance and aircraft limitations. Several levels of radar performance with corresponding altitudes are selected. Level number 1 corresponds to the best radar performance expected whereas level number 2 is a lower performance level. Radar characteristics are discussed more fully in Chapter II. The altitudes examined range from 15,000 feet to 50,000 feet. Preliminary analysis shows that the minimum barrier system cost would be attained if the aircraft flies higher than 15,000 feet. An altitude of 50,000 feet is selected as the maximum practical altitude for the DEW type of operation.

System Costs

Airplane

To determine costs, an airplane is divided into major components of structure, power plant, military load, and component spares. These components are costed by applying average cost per pound rates for corresponding items.

Based on a life expectancy of 5 years, an annual replacement cost of the airplane is determined. This cost is increased by the operating expenses of fuel, crew and maintenance to obtain the total annual cost.

Costs for crew and military load, normally included in the total annual airplane cost, are examined separately to reflect variations in the DEW and DEW & C barrier types in respect to those items that occur independently of the airplane configuration.

Crew

Airplane crews vary in size depending on the requirements of the mission involved, as shown in the preceding paragraphs. The elements of each crew are analyzed and the average monthly pay is determined for the number of

officers and enlisted men required. Estimated training costs are then added before establishing annual crew costs.

Military Load

Military loads considered in this study include radar, communications, navigation, crew, miscellaneous items, and in the case of DEW configuration, defense equipment as an option. A weighted rate per pound is determined by assigning applicable rates to each of the various types of items comprising each item of the military load.

Base

Base costs vary with the size and quantity of the based airplanes. A Class A Base is a major supporting base, furnishing complete logistic support from which forty 140,000-pound airplanes can conduct DEW and DEW & C barrier operations. A Class B Base is an auxiliary supporting or staging base for landing, refueling and line maintenance.

Further assumptions have been made as follows:

1. Quantities in excess of 40 airplanes that can be serviced on a single base vary inversely with take-off weight of the airplanes. (Following the dispersal principle it is assumed that separate facilities will be required as the quantity of based airplanes increases beyond a certain limit).
2. Cost of a base will not decrease below that for 20 airplanes.

To the cost of a base in the ZI, location factors are applied to reflect the additional logistic and maintenance expenses involved in maintaining bases in northern areas and overseas.

Summary

Total system cost, C_S, represents the summation of the foregoing elements in terms of 1955 dollars expressed as follows:

$$C_S = N(C_{\text{airplane}} + C_{\text{flight personnel}} + C_{\text{military load}}) + k(C_{\text{bases}})$$

where,

N = System quantity of airplanes

k = Base location factor

A detailed discussion of cost factors is given in Reference 28.

SUMMARY OF DEW RESULTS

This section deals with the effects on system cost and on the selection of optimum airplane systems of radar, aircraft, and tactical parameter changes. The optimum DEW system is determined for both single barriers and a network of barriers for two levels of radar performance and the characteristics tabulated. The selection of the system is accomplished by application of the measure of effectiveness.

Effect on System Cost of Radar and Communication Parameter Changes

Performance Level

The performance levels chosen are discussed in Chapter II. For the airplane analysis, design point airplanes are calculated using performance levels one and two for the reflector type antenna and performance level one for the retarded surface wave type antenna. This latter combination assumes that a very significant change in the state-of-the-art may be obtainable. This would enable one to carry a new type antenna in the smallest radome considered, with a radar system performance roughly equivalent to the 7.2 x 30 reflector antenna carried in the 7.5 x 37.5 radome.

Throughout this section, reference to the performance levels will be as follows:

Performance level 1 - Reflector antenna with no operational degradation

Performance level 2 - Reflector antenna with operational degradation

Performance level SW-1 - Retarded surface wave antenna with no degradation.

Figure V.3 is a plot of system cost versus performance level for a pattern 4 barrier of various lengths. The figure shows that for the shorter barriers the influence of performance level is not marked, but that as barrier length increases savings of nearly 20 per cent can be obtained if performance level SW-1 is achieved.

The characteristics of the aircraft designed for the different levels of performance vary quite widely, since the antenna size required changes. For example, if aircraft design is based on an SW-1 performance level, the ra-

28. R. H. Conklin. *Cost Analysis for Airborne Early Warning Barrier Systems.* Lockheed Memorandum Report 7093, Military Operations Research Division, Lockheed Aircraft Corporation, 15 April 1955. (CONFIDENTIAL)

dome carried is 4.8x20 feet. However, if a lower performance level is obtained the small antenna forces close aircraft spacings and the system becomes more expensive than if the design were based on this lower level of performance.

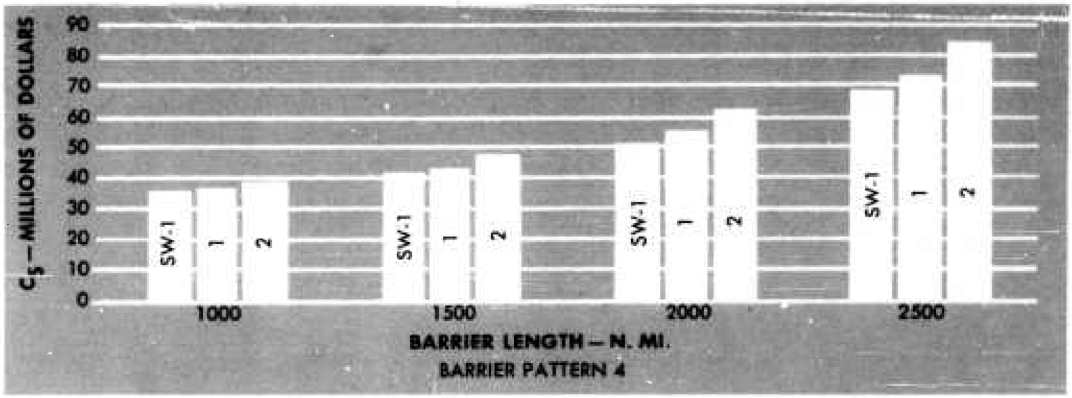


FIGURE V.3 — EFFECT OF RADAR PERFORMANCE LEVEL ON SYSTEM COST

Figure V.4 summarizes the results of calculations to determine the penalties incurred in designing for various levels of performance. The "penalty" is defined as the change in the cost of the system using the airplane designed for one level if another performance level is obtained, as compared to the system cost using the optimum design airplane for the level of performance actually attained.

For example, if design is based on level 2 and level 1 is attained the system cost is 47.7 million. If the airplane designed for level 1 is used the system cost is 42.9 million. Thus the penalty is $\frac{47.7 - 42.9}{42.9}$ or 11 per cent.

Examination of Figure V.4 indicates several important effects.

1. If a higher performance level is assumed (level SW-1) and is not attained the penalties that must be accepted are very serious - for some cases as high as 50 per cent.
2. If a low performance level is assumed (level 2) and is not attained, penalties of the order of 20 per cent will be incurred if significant changes in the state-of-the-art are achieved. If, however, improvements in maintenance and performance are achieved, the penalties incurred are nearly 12 per cent.

3. If good maintenance and performance are assumed (level 1), and are not achieved, the penalties are 2 to 3 per cent, except for the 2500-mile barrier. If a significant change in the state-of-the-art is achieved (level SW-1), the penalties are generally less than 10 per cent.

On the basis of these considerations it is difficult to arrive at a clear-cut decision on which performance level the aircraft system design must be based. The choice of the specific level to design for must rest upon the probability of obtaining given levels. In order to gain further insight into this problem, the influence of varying the probabilities of the occurrence of different levels of performance and a range of barrier lengths is examined. Using the values of Figure V.4 it is found that if the probability of occurrence of performance level 1 is approximately 15 per cent or greater it is better to design to this level.

EFFECT OF RADAR PERFORMANCE LEVEL CHANGES

BARRIER LENGTH	IF LEVEL DESIGNED FOR IS:	AND LEVEL OBTAINED IS:	THEN THE PERCENT PENALTY PAID IS:
1500	2	1	13.5
	2	SW-1	16.0
2000	2	1	13.0
	2	SW-1	24.5
2500	2	1	14.5
	2	SW-1	23.0
1500	1	2	0.5
	1	SW-1	2.0
2000	1	2	3.0
	1	SW-1	10.0
2500	1	2	17.5
	1	SW-1	7.0
1500	SW-1	2	7.0
	SW-1	1	7.0
2000	SW-1	2	26.0
	SW-1	1	21.0
2500	SW-1	2	50.0
	SW-1	1	31.5

FIGURE V.4

The effects of performance level on the selection of optimum systems are:

1. If radar performance levels can be strictly defined, airplanes designed exactly for these levels will result in minimum system costs.
2. If designs are based upon a high performance level (SW-1), and this level is not attained, serious penalties are incurred.
3. Unless there is a high probability (75-90 per cent) of obtaining level 2, there are less penalties in designing to level 1.

Operator Factor

The operator factor affects the spacing between aircraft, and this influences system cost. In general, it has only minor effect on the characteristics of the aircraft selected as optimums. Figure V.5 tabulates the difference in system costs for three different operator factors for performance level 2 and a 2000-mile barrier, pattern 8.

THE EFFECT OF OPERATOR FACTOR ON SYSTEM COST

RADOME SIZE (FEET)	OPERATOR FACTOR .05	0.10	0.50	INCREMENTAL CHANGE (PER CENT)
	SYSTEM COST (MILLIONS OF DOLLARS)			
4.8 x 20	91.0	82.3	76.6	7.0
6.3 x 31.5	73.6	69.1	65.4	6.0
7.5 x 37.5	66.0	62.4	58.7	6.0

FIGURE V.5

Since the airplane characteristics are only slightly affected and the overall system cost is changed by less than 10 per cent, all calculations are based upon an operator factor of 0.10.

Radar Type

One family of airplanes in the parametric studies is designed with an airplane carrying an S-band radar with a 7.2 x 30 antenna. As stated in Chapter II, the large S-band antenna, because of its narrow beamwidth, may be un-

suitable for search. For the purposes of illustration, however, this size antenna has been carried through the calculations.

Figure V.6 is a plot of optimum system costs for various barrier lengths for airplanes carrying an S-band or UHF radar operating at performance level, 2. This example is typical and shows that, regardless of barrier length, the optimum UHF system is always less expensive; and as barrier length increases the savings effected by use of UHF are very substantial.

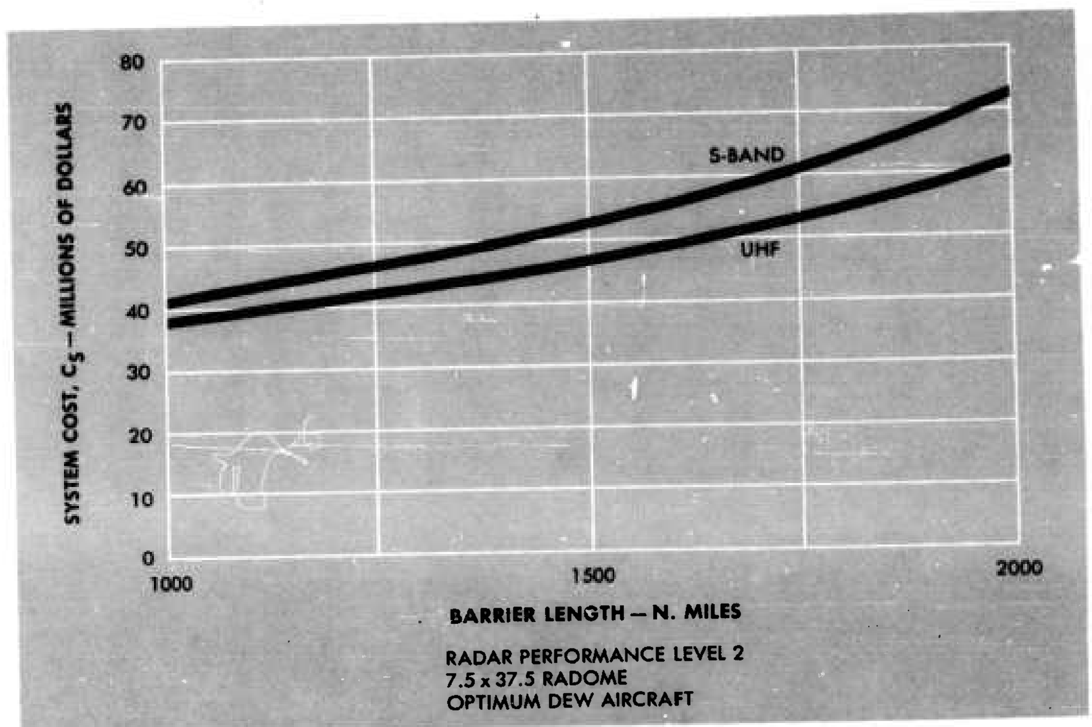


FIGURE V.6 — EFFECT OF RADAR TYPE ON SYSTEM COST

Radar Target Reflecting Area

The effect of changes in reflecting area can be quite significant. There are essentially two ways in which changes in reflecting area may affect the system performance. If the same level of probability of detection is required against a target with a smaller area such as a missile, the spacing between aircraft must be decreased. This increases the system cost.

If, however, the spacing of the aircraft remains constant, based upon the spacing for the jet bomber target, a lower probability of detection is achieved against the smaller target.

The penetration of a target of larger cross-section than that designed for will either increase the probability of detection or will allow increased spacings. The latter course of action is somewhat impractical because the aircraft designed to detect the jet bomber type target are near their maximum ceiling and if spacing is to be increased the search aircraft must fly at higher altitudes.

For the case of varying the spacing to insure a given probability of detection, the results of a sample calculation based on the following assumptions are shown in Figure V.7.

1) Barrier Length - 2000; 2) Performance Level - 2; 3) Barrier Pattern 8.

EFFECT OF VARYING RADAR TARGET AREA ON SYSTEM COST

ANTENNA SIZE	SPACING	N	COST OF SYSTEM FOR 1 m^2	COST OF SYSTEM FOR 7 m^2	PERCENT INCREASE
7.2 x 30	156	61.6	145.5	62.4	233
6 x 25	141	68.0	160.5	69.1	233
4 x 17.5	115	81.6	188.0	82.13	329

FIGURE V.7

The cost of a system spaced so as to obtain a 0.9 probability of detection on a 1 square meter target is more than double that for a 7 square meter target.

For the case of maintaining the spacing based upon a 7 square meter target, the probability of detecting a missile target entering the barrier at random is approximately 0.40.

Communications

It is difficult to assign specific values to the reduction in spacing necessary to insure reliable communications between early warning aircraft. The influence of poor communication performance is to require some sort of communication relay vessels in the barrier or to force decreases in spacing between aircraft.

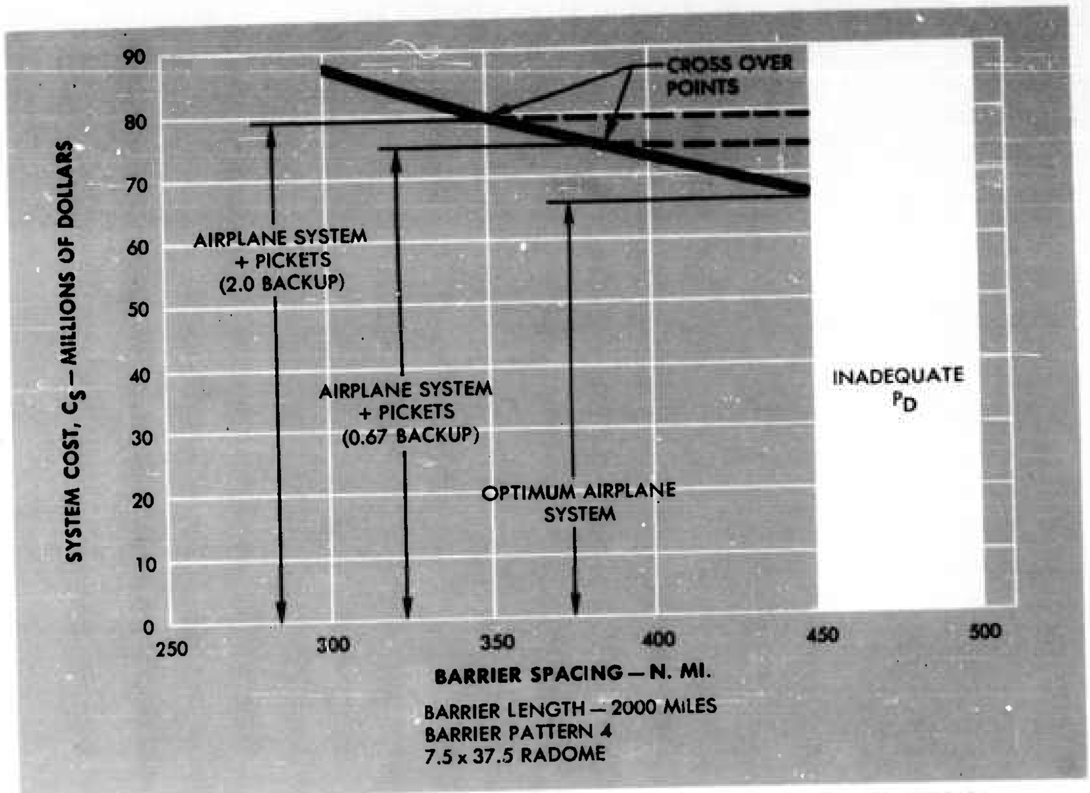


FIGURE V.8—EFFECT OF CHANGING SPACING TO ACHIEVE COMMUNICATIONS

No detailed analysis on the cost of picket ships has been made in the course of this study but previous studies have indicated that the cost of operating a destroyer escort type vessel is approximately $110,000 to $120,000 per month. Back-up factors of 0.67 and 2.0 are examined. See References 29, 30 and 31. Figure V.8 indicates the effect on systems cost of decreasing spacing in order to insure reliable UHF communications with conventional equipment. In addition, an indication is given of the cost of adding picket

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29. *Analysis of Carrier-Based ASW Weapon Systems for 1957 to 1962.* Fourth Interim Report of Air Aspects of Anti-Submarine Warfare. LAC Report 8517. Military Operations Research Division, Lockheed Aircraft Corporation. 17 December 1953. (SECRET)

30. *Systems Analysis of Helicopters and Airships for Anti-Submarine Warfare for 1959 to 1964.* Fifth Interim Report of Air Aspects of Anti-Submarine Warfare. LAC Report 9998. Military Operations Research Division, Lockheed Aircraft Corporation. 1 December 1954. (SECRET)

31. *Evaluation of Routes for Eastern Extension of DEW Line.* Joint USN/USAF Feasibility Study Group, Working Paper of Sub-Committee. 1955.

ships to the barrier and of the point at which it is better to add communication ships than to further decrease the spacing. For example, if a back-up factor of 2.0 is used, it is less costly to decrease spacing between aircraft to approximately 350 miles than to add picket ships. If spacing must be decreased to less than 350 miles, it is advantageous to add ships and return to aircraft spacings of 450 miles.

As discussed in Chapter III and in Reference 32, it appears feasible to obtain communications without materially decreasing the spacing between aircraft. Therefore, adding picket ships solely to maintain communications seems to be of questionable value.

General Factors Affecting System Cost

Barrier Length

Because of the interaction of many variables, the effect of barrier length on system cost is not linear. The criteria of selection of a barrier has often been based on cost per given length, and the cost of other lengths has been obtained by proportion. Figure V.9 shows the effect of barrier length on system cost for various barrier configurations.

Over-all system costs do not vary directly as a function of barrier length for any of the barrier types investigated. This is true even for those barriers where the number of airplanes required is a direct proportion of barrier length. The number 2 barrier most nearly approximates a linear function.

Barrier Pattern

One of the most important variables affecting system cost is the barrier pattern employed. As described earlier, the distant early warning barriers are all single lines using the shift technique except for barrier 8 which uses the oscillating technique. Figure V.9 shows the effects of selection of the barrier pattern on the system cost.

For the barrier length of 1000 miles, the influence of barrier pattern is negligible. The cost of obtaining range in the aircraft at this level is not significant and the base costs are nearly constant because of the lower limit set upon these costs.

32. A. G. Bogosian and E. S. Quilter, *Communications and Navigation in Airborne Early Warning Barriers.* Lockheed Memorandum Report 7094. Military Operations Research Division, Lockheed Aircraft Corporation. 1 July 1955. (SECRET)

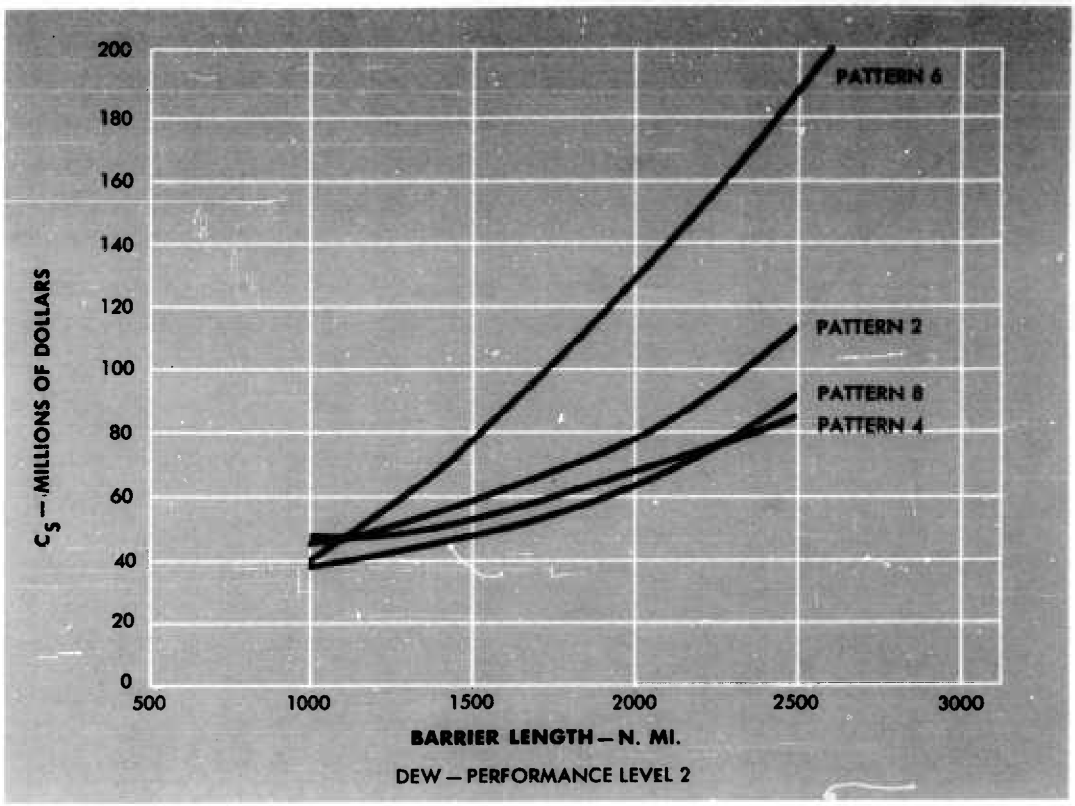


FIGURE V.9 — EFFECT OF BARRIER LENGTH AND PATTERNS ON SYSTEM COST

As the barrier length increases, the significance of the selection of proper barrier type becomes most apparent. Barrier 6 becomes spectacularly expensive for the reason that, while the number of planes required goes up in almost a linear relationship, the cost per airplane rises very rapidly as the range requirements increase.

While barrier 2 is competitive for barrier lengths between 1000 and 1500 miles, as barrier length increases it becomes more expensive than barriers 4 or 8 by 15 to 30 per cent.

Of the various barriers considered, barriers 4 and 8 are essentially equal in cost but the characteristics of the airplanes required to fly these barriers are quite different. This will be examined further when considering the optimum airplane for a network of barriers.

Endurance

As noted previously, the endurance of the aircraft determines the crew size required, and the crew size in turn partially determines the military load. The number of airplanes required for the barriers using the shift technique is affected by the range of the aircraft and therefore by the endurance. It was thought that there might be an advantage in designing a long-endurance aircraft, thus reducing the force requirements. Figure V.10 lists the system costs for the optimum aircraft for less than 18 hours and more than 18 hours endurance for various barrier patterns.

SYSTEMS COSTS FOR TWO LEVELS OF ENDURANCE

BARRIER LENGTH	1000		1500		2000		2500	
ENDURANCE	0-18	18	0-18	18	0-18	18	0-18	18
BARRIER	SYSTEM COST — MILLIONS OF DOLLARS							
2	41.7	48.8	63.9	75.5	90.9	107.6	121.4	143.8
4	43.0	48.7	55.3	64.8	70.2	83.8	93.8	111.9
6	39.3	47.0	76.4	85.6	*	138.6	*	213.4

*NO DESIGN POINT AIRPLANES

FIGURE V.10

While these are selected numbers, they are typical of the results. In all cases the savings effected through reduction in force requirements, obtained by increasing the endurance of the aircraft, are more than offset by increased costs of the airplane. Consequently, all airplanes selected as optimum have endurances of less than 18 hours, except when the length of the barrier dictates endurances of greater than 18 hours.

Military Load

Figure V.11 gives some indication of the increase in the cost of the airplane for a constant range and altitude as the military load increases. It is

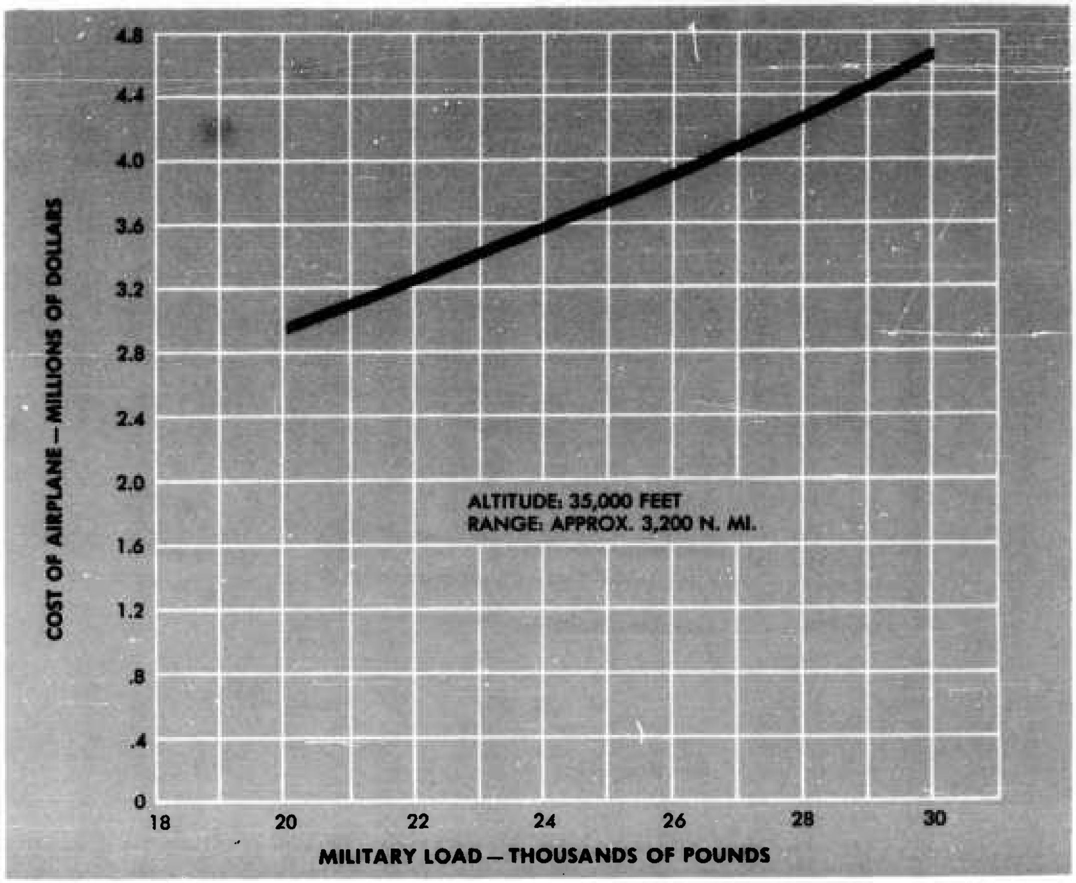


FIGURE V.11 — EFFECT OF MILITARY LOAD ON AIRPLANE COST

seen that the airplane cost increases almost linearly with increases in military load. This is shown also in Reference 33.

Altitude

The altitude at which the DEW airplane is flown is a compromise between aircraft and radar performance. The effect of altitude on the cost of the system is very significant since the spacing increases and the force requirements decrease as altitude increases. The increase in the cost per airplane as a

33. *Analysis of Land-Based Airplane, Single-Package ASW Weapon Systems for 1956.* Second Interim Report of Air Aspects of Anti-Submarine Warfare. LAC Report 7763. Military Operations Research Division, Lockheed Aircraft Corporation. 1 February 1951. (SECRET)

function of altitude is small at the lower military loads and lower altitudes, but as both military load and altitude increase the airplane costs increase significantly. Thus as we go to altitudes near the limit of performance the savings effected by the decrease in force requirements are cancelled out by increase in airplane costs. Figure V.12 shows the increase in airplane costs as a function of altitude for two radome sizes and for given military loads, and Figure V.13 indicates the change in system cost as a function of altitude. It is seen that over-all system cost minimizes for a flight altitude of approximately 35,000 feet.

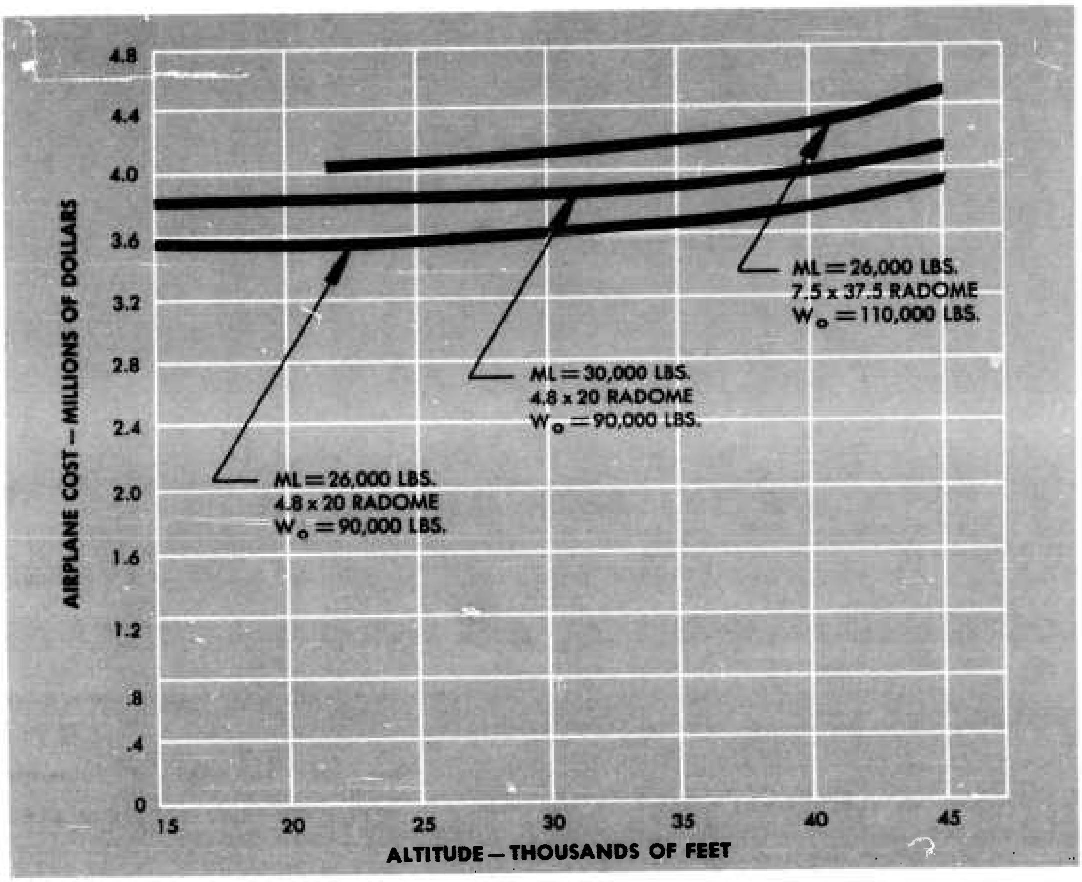


FIGURE V.12 — EFFECT OF ALTITUDE ON AIRPLANE COST

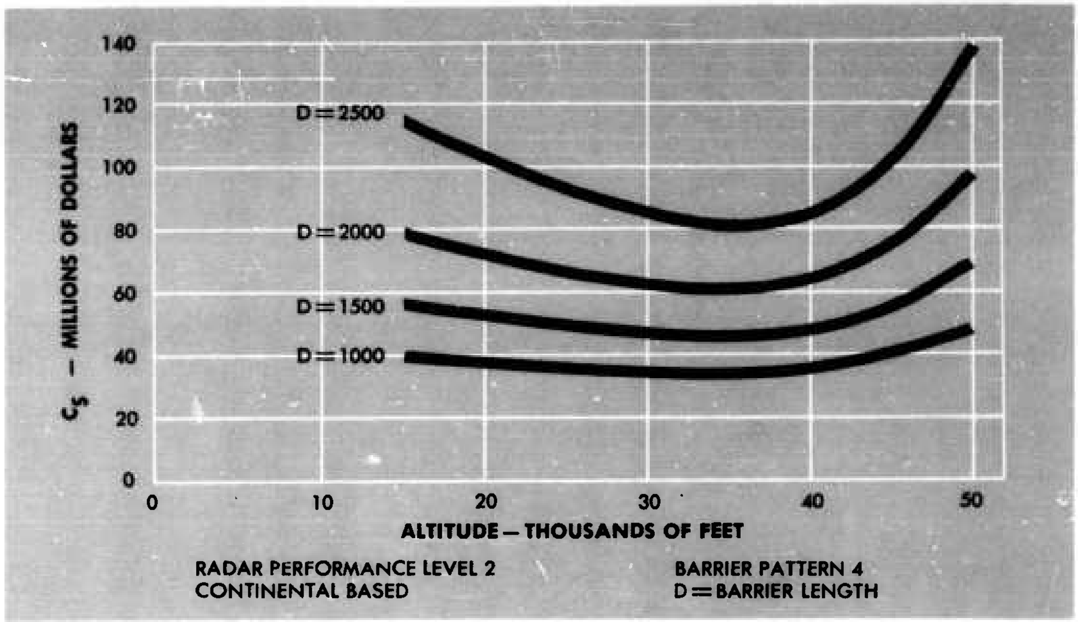


FIGURE V.13—SYSTEM COSTS VS. ALTITUDE

Utilization

In all the calculations for system cost, the formulas for determining the number of airplanes required in the system are based upon an airplane operational utilization of 150 flying hours per month. This indicates that approximately five airplanes are required in the over-all system in order to maintain one in flight.

The most significant effect of utilization is on the number of airplanes required in the system. The number of airplanes required is an inverse function of utilization, that is, if utilization is halved the number of airplanes required is doubled. Within limits, the base costs are also functions of N. These effects are shown in Figure V. 14 for barrier 4 of 1500 miles length.

Navigation

Poor airplane navigation system accuracy can result in increases in system cost in two ways:

1. If the navigation errors are such that gaps appear in the line, the spacing between aircraft must be decreased until even with maximum navi-

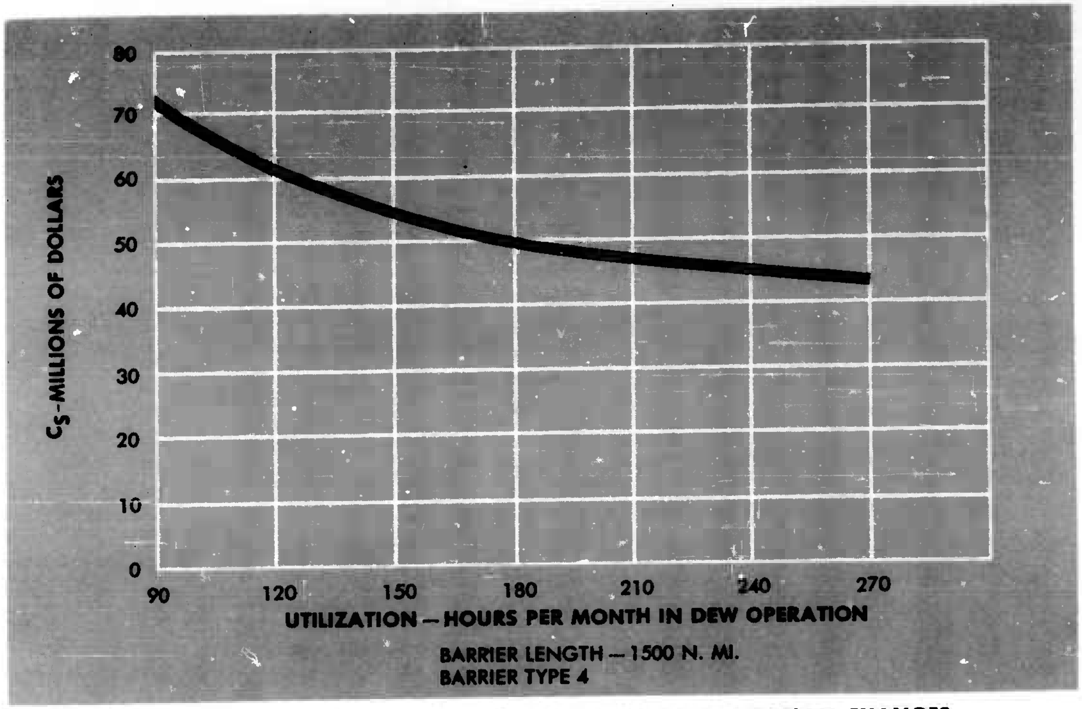


FIGURE V.14 — EFFECT ON SYSTEM COST OF UTILIZATION CHANGES

gation errors the integrity of the line is maintained. This decreased spacing results in a more expensive system since, as spacing decreases, the system cost increases. As previously stated the spacing was chosen as 1.9 times the lateral range at which the probability of detection is 0.7. Thus, for the large spacings, the overlap provided is in the order of 15 to 25 miles. As stated in Chapter III, this accuracy appears obtainable with planned navigation systems. If, however, such navigational accuracies are difficult to obtain and the overlap is doubled, the system cost will be increased by not more than five per cent. It must be realized, however, that the poor navigation will degrade the position reporting accuracy of the system.

2. If the inherent navigation accuracy of the airplane system is poor, picket ships can be added to act as reference stations. In this case, the aircraft would not use their installed system but would maintain position by radar fixes on the picket ships. If the costs of the pickets are charged to the warning system, the over-all system cost would be materially increased, as

discussed in the communication section of this chapter. The position reporting accuracy would not be degraded in the same degree as for the system utilizing decreased spacing.

As shown previously the system cost for a 1500-mile barrier 4 is approximately 54 million dollars annually. If it is assumed that two navigation ships are used in the barrier (i.e. 500 miles between ships) the cost of providing such ships would be 4.8 million dollars a year. This increase of annual cost from 54 to 58.8 million is an increase in over-all system cost of approximately 10 per cent.

It appears, then, that there is little justification in providing picket ships if their sole purpose is to act as navigation checkpoints; it is less costly to fly the aircraft at closer spacings.

Self Defense Measures

There are several ways that self-defense of early warning airplanes can be provided. The two methods examined here are adding defense missiles or providing a burst speed capability. It must be realized that these are examined in the cold war framework and the costs are those involved in providing this capability. No attempt is made here to evaluate the worth of such defense, or the reduction in combat attrition that might be effected.

1. Defense Missiles

One method sometimes proposed is to provide some measure of defense by adding short-range missiles. No attempt is made here to evaluate the worth of such defense, nor is any detailed analysis made of the feasibility of adding such missiles. Discussions were held with personnel at NADC and in the Bureau of Aeronautics and the consensus is that one of the present missiles could be adapted for this purpose. In this section, only the influence on system cost is examined. In general, this can be shown as an increase in military load and personnel costs for the system.

2. Escape Burst Speed

A second method of securing self-defense is to incorporate an escape burst speed in the airplane. A limited analysis quickly indicated that the cost of an escape speed capability would be prohibitive. For a typical case the addition of burst speed increases the airplane system cost by approximately 63 per cent and over-all system cost by nearly 40 per cent.

The results of calculations are shown in Figure V.15 for a 1500- and 2500-mile pattern 4 barrier.

COST OF ADDING DEFENSE MISSILES

BARRIER LENGTH	1500		2500	
	OPTIMUM	DEFENSE MISSILE	OPTIMUM	DEFENSE MISSILE
W_o	90,000	110,000	110,000	130,000
MILITARY LOAD	26,000	32,000	26,000	32,000
C_S (MILLIONS)	53.8	61.2	84.7	99.7
COST INCREASE	—	7.4	—	15.0
% COST INCREASE	—	13.8	—	17.2

FIGURE V.15

The adding of defense missiles increases the cost of the airplanes in the system by approximately 20 per cent and increases the over-all system cost by approximately 15 per cent.

Use of High Energy Fuel in Early Warning Aircraft

Consideration has been given to possible advantages in extending range capability by the use of high energy fuel in early warning aircraft employing turboprop engines. It is contemplated that limited amounts of high energy fuels might be available by 1960. It is doubtful that such high energy fuel could be made available for early warning aircraft except possibly for short periods during extreme emergencies. In addition, developmental problems such as toxicity and a tendency to form deposits on turbine blades must be overcome before these fuels can be put into use. Nevertheless, it appeared desirable to investigate both the improvement in performance and the expected effect on the cost of an early warning aircraft system if such high energy fuel should be available.

Effect on Aircraft Performance and Cost

Gross weights required to obtain various ranges and the resulting effect on annual system cost of an early warning aircraft carrying a military load

of 24,000 pounds are illustrated on Figure V.16. The middle solid line represents the performance of a series of optimum design airplanes using normal hydrocarbon jet fuel JP-4. Each aircraft on this curve has an optimum design for the range shown as obtained from the parametric analysis.

The lower broken line on Figure V.16 illustrates the decrease in gross weight or the increase in range resulting when the aircraft is designed to take advantage of a high energy fuel with a heating value about 45 per cent greater than that of JP-4.

If this high energy fuel could be obtained at the same cost as the JP-4 fuel, a substantial decrease in the system cost would result from the decrease in gross weight required to obtain the same range. However, the high energy fuel would probably cost at least $0.50 per pound in 1960. This is 25 times the current cost of JP-4 fuel and results in a higher system cost per aircraft as shown by the upper broken line in Figure V.16.

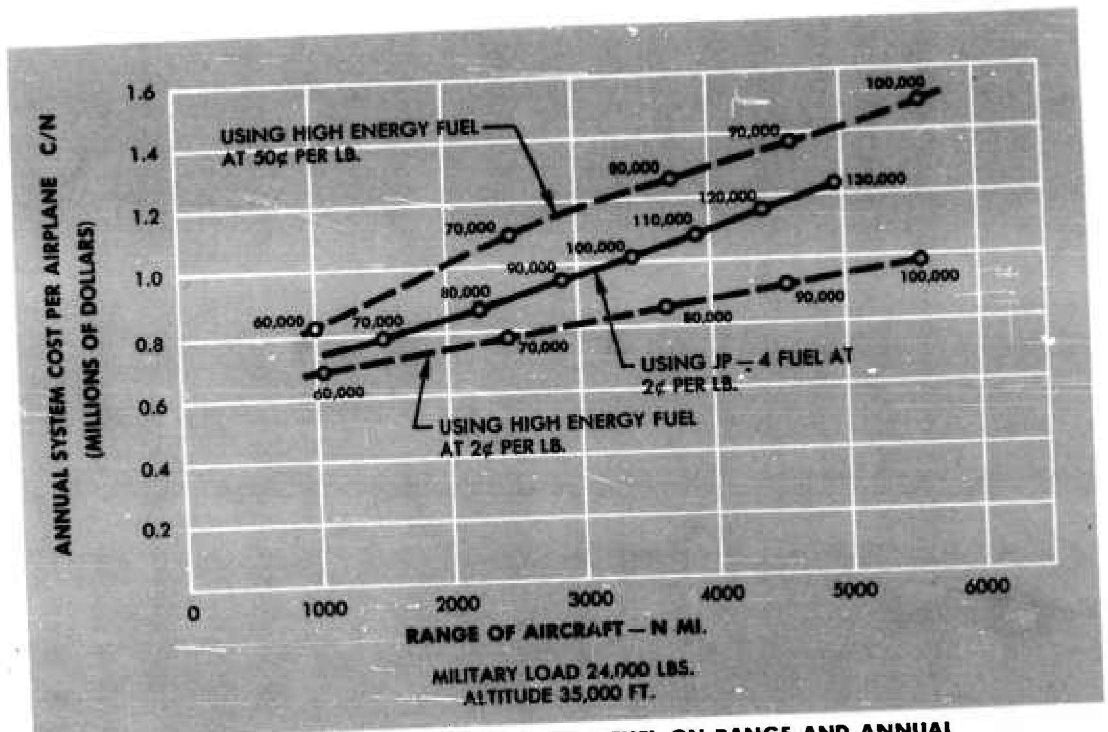


FIGURE V.16 — EFFECT OF HIGH ENERGY FUEL ON RANGE AND ANNUAL SYSTEM COST OF EW AIRPLANES

Airplane System Cost

This cost per airplane must be multiplied by the force requirement (N) to obtain the total airplane cost for any particular barrier under consideration. These annual system costs are illustrated in Figure V. 17 for both

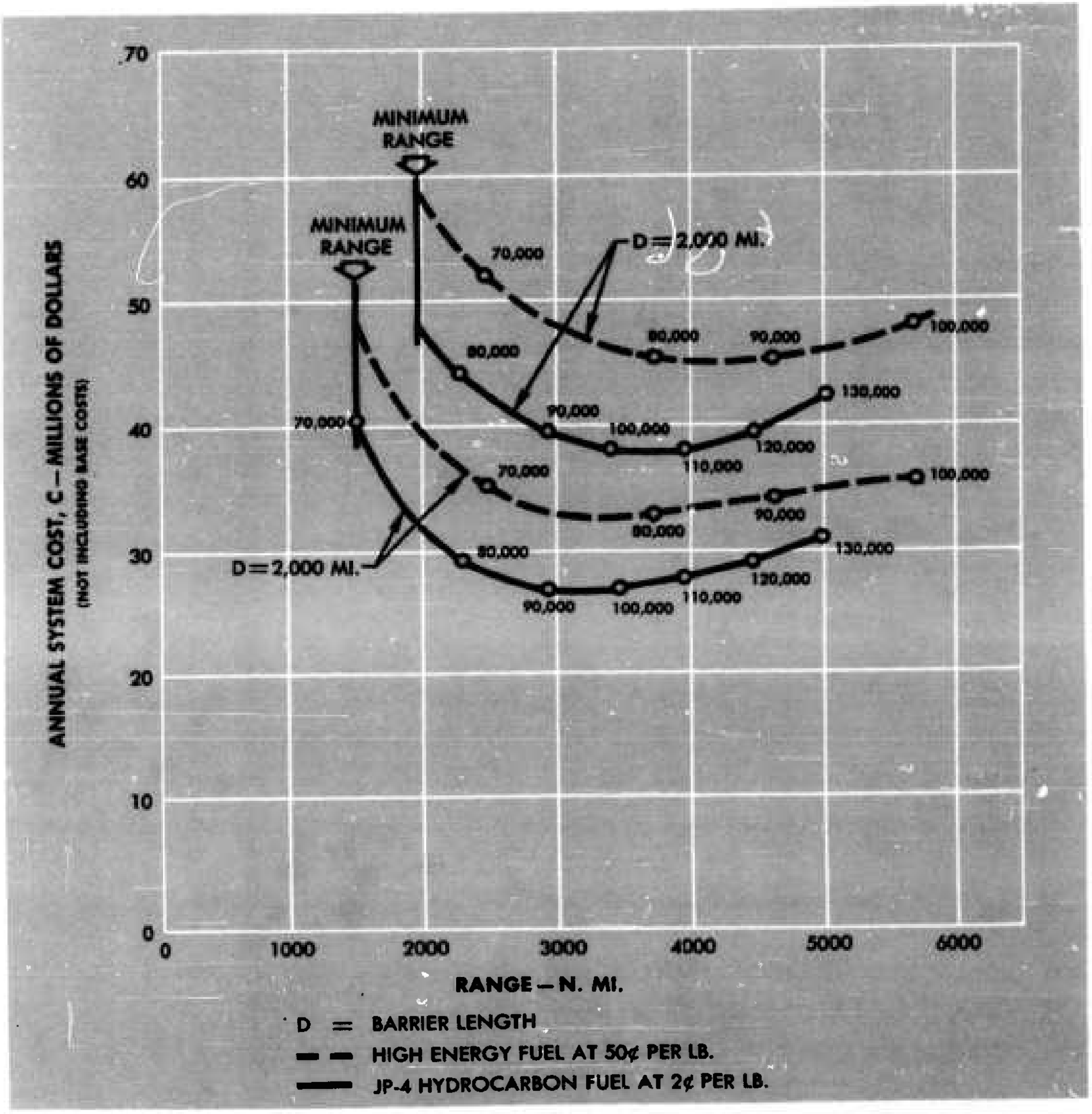


FIGURE V.17 — EFFECT OF HIGH ENERGY FUEL ON ANNUAL SYSTEM COST FOR TYPE 4 BARRIER

JP-4 and high energy fuels for 1500, 2000, 2500 and 3000 mile barrier lengths in a Type 4 barrier. Range is an advantage in this type of barrier primarily because the aircraft orbit on station and take advantage of extra endurance beyond that required to fly the minimum barrier distance. Figure V.17 illustrates that when employing a Type 4 barrier, it is an advantage to have an airplane with a range capacity about 1500 miles greater than the minimum flight distance. This gives approximately a 50 per cent decrease in the force requirement (N) as shown in Figure V.18.

TYPE 4 BARRIER WITH 500 MI. SPACING

BARRIER DISTANCE (D) (N. MI.)	MINIMUM RANGE		OPTIMUM RANGE		OPTIMUM GROSS WT.	
	MILES	(N)	MILES	(N)	JP-4	H. E. FUEL
1500	1000	52	2500	21	83,000	70,000
2000	1500	57	3000	29	91,000	74,000
2500	2000	64	3500	37	101,000	78,000
3000	2500	72	4000	46	111,000	82,000

FIGURE V.18

From Figure V.17 it appears that, if an aircraft has adequate range on regular hydrocarbon fuel, there is no cost advantage in employing high energy fuel. The uncertainty of availability, cost and performance of high energy fuels that may be perfected by 1960 makes it inadvisable to propose designing early warning aircraft for operation specifically on high energy fuel. However, potential advantages of this fuel as a range or load extender should be kept in mind. The additional range potential could be an advantage in longer barrier operations that might be required in the future, and also in making these aircraft more useful for fleet support operations where long endurance may be desirable. Certain of the proposed high energy fuels apparently could be made interchangeable with JP-4 fuel if the aircraft fuel system is designed with this in mind.

Characteristics of Optimum Systems for Given Barrier Lengths

The previous sections have examined numerous factors which affect system cost. Certain of these have a negligible effect and do not materially influence the final selection. The important factors to be considered, and the

values chosen, in selection of the optimum systems, are:

1. Pattern 4 or 8 barrier.
2. Radar level of performance 1. For purposes of comparison results for level 2 are also shown.
3. The UHF radar.
4. Aircraft with endurance of less than 18 hours.
5. Radome size of 6.3 x 31.5, housing a 6 x 25 foot antenna.

With these factors considered, the optimum airplanes are chosen. The characteristics of these airplanes and the total system cost are shown in Figure V.19 for both levels of radar performance.

CHARACTERISTICS OF AIRPLANE SYSTEMS

	BARRIER LENGTH	BARRIER PATTERN	RADOME SIZE *	W_e	RANGE	TOTAL FLIGHT CREW	N	C_S
RADAR PERFORMANCE LEVEL 1	1000	4	1	60	1840	512	18	41.9
	1000	4	2	75	2110	352	13	39.4
	1000	8	1	60	1840	374	13	37.6
	1000	8	2	75	1960	268	10	36.2
	1500	4	1	75	2700	776	28	53.4
	1500	4	2	90	2940	542	20	48.7
	1500	8	1	75	2700	560	20	45.8
	1500	8	2	90	2720	404	14	42.9
	2000	4	1	75	2690	1186	43	67.9
	2000	4	2	90	2940	816	29	60.2
	2000	8	1	130	3710	1386	27	69.9
	2000	8	2	130	3580	538	19	55.2
	2500	4	1	90	3060	1578	56	96.7
	2500	4	2	90	2940	1170	42	74.3
	2500	8	1	180	4800	1734	33	94.2
	2500	8	2	180	4730	1248	24	76.9
RADAR PERFORMANCE LEVEL 2	1000	4	2	75	2170	458	16	43.0
	1000	4	3	90	2430	374	13	42.1
	1000	8	2	75	2080	352	13	39.0
	1000	8	3	75	1590	298	11	37.6
	1500	4	2	90	2890	712	25	55.3
	1500	4	3	90	2430	646	23	53.8
	1500	8	2	90	2890	528	19	47.7
	1500	8	3	110	3060	446	16	48.6
	2000	4	2	90	2890	1076	38	70.2
	2000	4	3	110	3280	854	31	67.4
	2000	8	2	130	3680	1306	25	69.1
	2000	8	3	150	3600	594	21	62.4
	2500	4	2	110	3560	1356	48	93.8
	2500	4	3	110	3280	1200	43	84.7
	2500	8	2	180	4770	1634	31	91.9
	2500	8	3	220	5110	1380	27	91.4

*(1) 4.8 x 20 (2) 6.3 x 31.5 (3) 7.5 x 37.5

FIGURE V.19

A study of the table indicates that the characteristics of the airplanes in the optimum systems vary quite widely. Figure V.20 is extracted from Figure V.19 and shows the characteristics of the optimum systems for each barrier length and for two levels of radar performance.

These values give some feeling for the influence of range and the number of airplanes on the system cost. Even though barrier 8 requires the

CHARACTERISTICS OF OPTIMUM SYSTEM FOR GIVEN BARRIER LENGTHS

PERFORMANCE LEVEL 1

BARRIER LENGTH	1,000	1,500	2,000	2,500
BARRIER PATTERN	8	8	8	4
TAKE-OFF WT. (lbs.)	75,000	90,000	130,000	90,000
RADOME SIZE (ft.)	6.3 X 31.5	6.3 X 31.5	6.3 X 31.5	6.3 X 31.5
RANGE (n. mi.)	1960	2720	3580	2940
ENDURANCE (hrs.)	10.3	14.3	16.7	13.7
VELOCITY (kts.)	200	200	225	225
AIRPLANE COST (millions of dollars)	3.25	3.62	4.73	3.59
NUMBER OF AIRPLANES	10	14	19	42
SYSTEM COST (millions of dollars)	36.2	42.9	55.2	74.3

PERFORMANCE LEVEL 2

BARRIER LENGTH	1,000	1,500	2,000	2,500
BARRIER PATTERN	8	8	8	4
TAKE-OFF WT. (lbs.)	75,000	90,000	150,000	110,000
RADOME SIZE (ft.)	7.5 X 37.5	6.3 X 31.5	7.5 X 37.5	7.5 X 37.5
RANGE (n. mi.)	1590	2890	3600	3280
ENDURANCE (hrs.)	7.4	15.2	16.8	15.4
VELOCITY (kts.)	225	200	225	225
AIRPLANE COST (millions of dollars)	4.21	3.48	5.41	4.21
NUMBER OF AIRPLANES	11	19	21	43
SYSTEM COST (millions of dollars)	37.6	47.7	62.4	84.7

FIGURE V.20

least number of airplanes, it requires an airplane with substantial range as the barrier length increases. This increased range requirement dictates larger gross weight airplanes, until for the 2500-mile barrier the savings effected by the small number of airplanes are offset by the costs of the larger airplanes.

Optimum System Characteristics for a Network of Barriers

It is impractical to procure a different airplane for every barrier length. The choice must be made based upon the airplane that will fly any given length barrier or network of barriers for the minimum cost.

For networks consisting of two barriers, an airplane, designated "A" for the moment, is clearly best. Airplanes A, B and C are the optimum airplanes selected for single barriers of a given length. The average penalty for two barrier networks using airplane A is approximately 0.3%; airplane B, its closest competitor, has an average penalty of 6.5%; and airplane C has an average penalty of 30%.

The result of using airplanes A, B and C in three and four barrier networks is shown in Figure V.21. Here again, the use of airplane A results in the lowest cost. The results shown are for a radar performance level 1, but similar results occur if performance level 2 is used.

EFFECT OF USING A SINGLE AIRPLANE IN A THREE AND FOUR BARRIER NETWORK

	THE COST USING AIRPLANES		
IF THE NETWORK IS:	A	B	C
1000 – 1500 – 2000	141.0	144.5	142.9
1000 – 1500 – 2500	155.1	172.4	163.2
1000 – 1500 – 2500	172.0	179.2	182.8
1500 – 2000 – 2500	177.8	186.7	188.2
1000 – 1500 – 2000 – 2500	215.3	227.6	225.7

FIGURE V.21

Selection of Best DEW Airplane System

The penalties incurred in selecting a single airplane for the various barriers are surprisingly small. The penalty in selecting a single airplane

instead of optimum airplanes for each barrier is in the order of four per cent. When one considers that purchase of a single type airplane would tend to decrease the individual airplane cost because of the effects of moving down the learning curve, even the four per cent penalty will tend to disappear.

However, important penalties can occur unless airplane characteristics and barrier types are very carefully fitted. If a single airplane is chosen the length of the barrier to be flown will dictate the barrier pattern to be flown to obtain the minimum cost.

Several other factors may enter into the selection of the optimum system. If a base cannot be established at one extremity of the barrier, pattern six must be flown. This, in general, will result in significant increases in the size of the aircraft and the cost of the system for other than 1000-mile barriers.

Another factor to be considered is the drain on the number of trained personnel that will result when these barriers are put in operation. Difficulties experienced by the armed forces in retaining qualified personnel indicate that the system using the least personnel would be singularly attractive. In general, the lowest cost system involves the least number of aircraft which, in turn, requires the smallest number of personnel.

The optimum distant early warning barrier system has the characteristics shown in Figure V.22 for each of the levels of radar performance assumed. These optimum airplanes have the capability of flying a single base barrier pattern (pattern 6) approximately 1500 miles in length. Certain of the barriers now contemplated are of greater length than this and there are advocates of the single base system. It is interesting to note that if one selects the airplane with range adequate to fly a 2500-mile barrier, non-stop, one must pay a penalty of 15 per cent to 20 per cent of the system cost depending on the barrier network assumed.

The characteristics of the optimum airplanes for the two different levels of radar performance are somewhat similar. The higher level of radar performance enables one to select an airplane with a smaller antenna and the corresponding lighter gross weight. As shown previously, if the probability of attaining the higher level of radar performance is at least 15 per cent, the selection of the system should be based on this higher level.

OPTIMUM DISTANT EARLY WARNING SYSTEM CHARACTERISTICS

SYSTEM CHARACTERISTICS	RADAR LEVEL 1	RADAR LEVEL 2
TAKE-OFF WEIGHT (lbs.)	90,000	110,000
RADOME SIZE (ft.)	6.3 x 31.5	7.5 x 37.5
CRUISE SPEED (kts.)	225	225
COMBAT RANGE (n. mi.)	2,940	3,280
ENDURANCE (hrs.)	13.7	15.4
ASPECT RATIO	14	14
WING LOADING (lbs/sq. ft.)	40	40
CRUISE ALTITUDE (ft.)	35,000	35,000
TOTAL FLIGHT PERSONNEL (2000-mile barrier)	816	854
AIRPLANE COST (millions of dollars)	3.60	4.21

OPTIMUM BARRIER TYPE

BARRIER LENGTH (n. mi.)		
1000	8 	8 
1500	8 	8 
2000	4 	4 
2500	4 	4 

BARRIER COST
(MILLIONS OF DOLLARS)

BARRIER LENGTH (n. mi.)				
1000	37.5	(36.2)	40.5	(37.6)
1500	43.3	(42.9)	47.7	(47.7)
2000	60.2	(55.2)	67.4	(62.4)
2500	74.3	(74.3)	84.7	(84.7)

NUMBERS IN PARENTHESES ARE FOR THE SINGLE OPTIMUM AIRPLANE FOR THAT BARRIER LENGTH.

FIGURE V.22

SUMMARY OF DEW & C RESULTS

This section will discuss airplane systems which have a control as well as a search capability. It must be emphasized that these are airplanes that have a selected amount of control capability and then an optimum airplane is selected with this level of control. No optimization has been made of the amount of control necessary, but the subject has been examined briefly in Appendix D.

The addition of a control function exerts certain definite influences on systems. Military loads are heavier; crew requirements are increased; and changes in radar type, airplane design and tactical parameters all affect the final selection of the optimum system. In this section, the best early warning system with selected control ability is determined both for single barriers and for a network of barriers. Two levels of radar performance are employed. The optimum system is selected by application of the measure of effectiveness. Because the remarks in the DEW section are generally applicable to DEW & C, discussion of the various effects is brief, and is confined to the material changes which occur in the transposition from a warning only to a warning and control function.

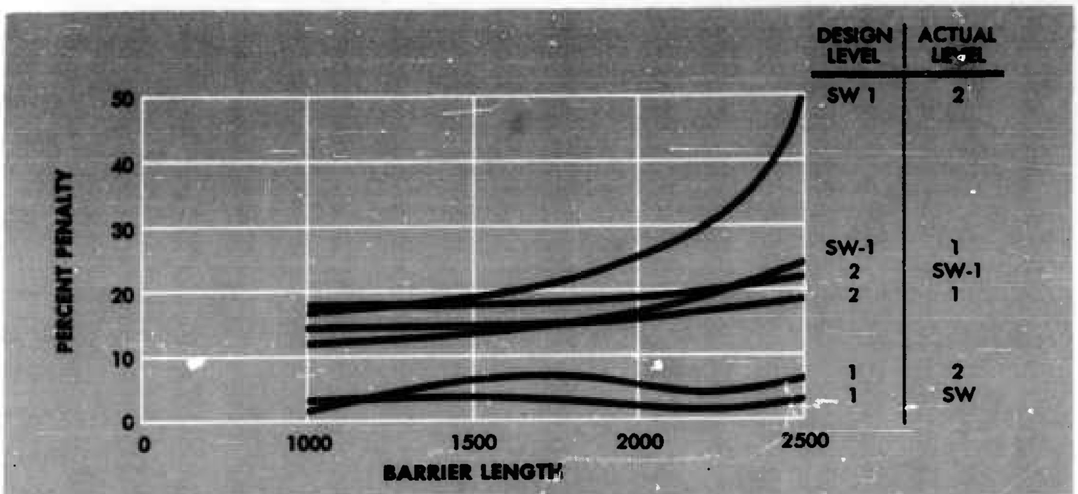
As in the DEW case, certain penalties are incurred if one level is designed for and another is obtained. The designer attempts to minimize the penalties that might result.

The penalty paid in designing for one level of radar performance and having to use this design in a different level is shown in Figure V.23. Here, the lowest penalty occurs when the design is directed toward performance level 1. A penalty of less than 7 per cent is incurred in designing for performance level 1 and using the design if levels 2 or SW-1 are achieved.

Figure V.23 indicates that for the DEW & C aircraft, the decision to design for performance level 1 is quite clear-cut.

Height Finding Capability

The DEW & C airplane contains search radar equipment, and a height finding system for the control function. Height finding range limitations require a reduction in the spacing. The spacing for control in a UHF system is assumed to be 70 per cent of the spacing distance used in the DEW analysis.



NOTE: 1 — RADAR PERFORMANCE LEVEL 1
2 — RADAR PERFORMANCE LEVEL 2
SW — 1 — SURFACE WAVE ANTENNA PERFORMANCE LEVEL 1

FIGURE V.23 — PENALTIES INCURRED FOR CHANGE IN PERFORMANCE LEVEL

Changing this spacing increases the number of airplanes required, and hence system cost. The quantitative effect of this radar spacing reduction factor is shown in Figure V.24. This figure compares force requirements with and without the 0.7 spacing reduction factor.

All results in the DEW & C systems analysis to follow are based upon this reduced spacing.

Radar Type

The effect on system cost of radar type for barrier patterns one and five is shown in Figure V.25 for a performance level of two. This figure shows, as in the case for plain DEW mission, that the use of S-band radar always results in greater system cost for all barrier distance than UHF radar.

Radar Target Reflecting Area

The influence of radar reflecting area on system cost for the DEW & C system is essentially the same as occurs in the DEW system. Because the DEW & C system has two lines of aircraft, this barrier has a probability of 0.99 of detecting a penetrating target of 7 square meters. If a target of 1

square meter is assumed, then in order to maintain the same probability ot detection the aircraft spacing must be reduced. The results of a typical calculation are listed in Figure V.26.

The probability of detecting a 1 square meter target which enters the barrier at random, and of maintaining the same system cost (spacing for $7m^2$ target) is reduced to approximately 0.7.

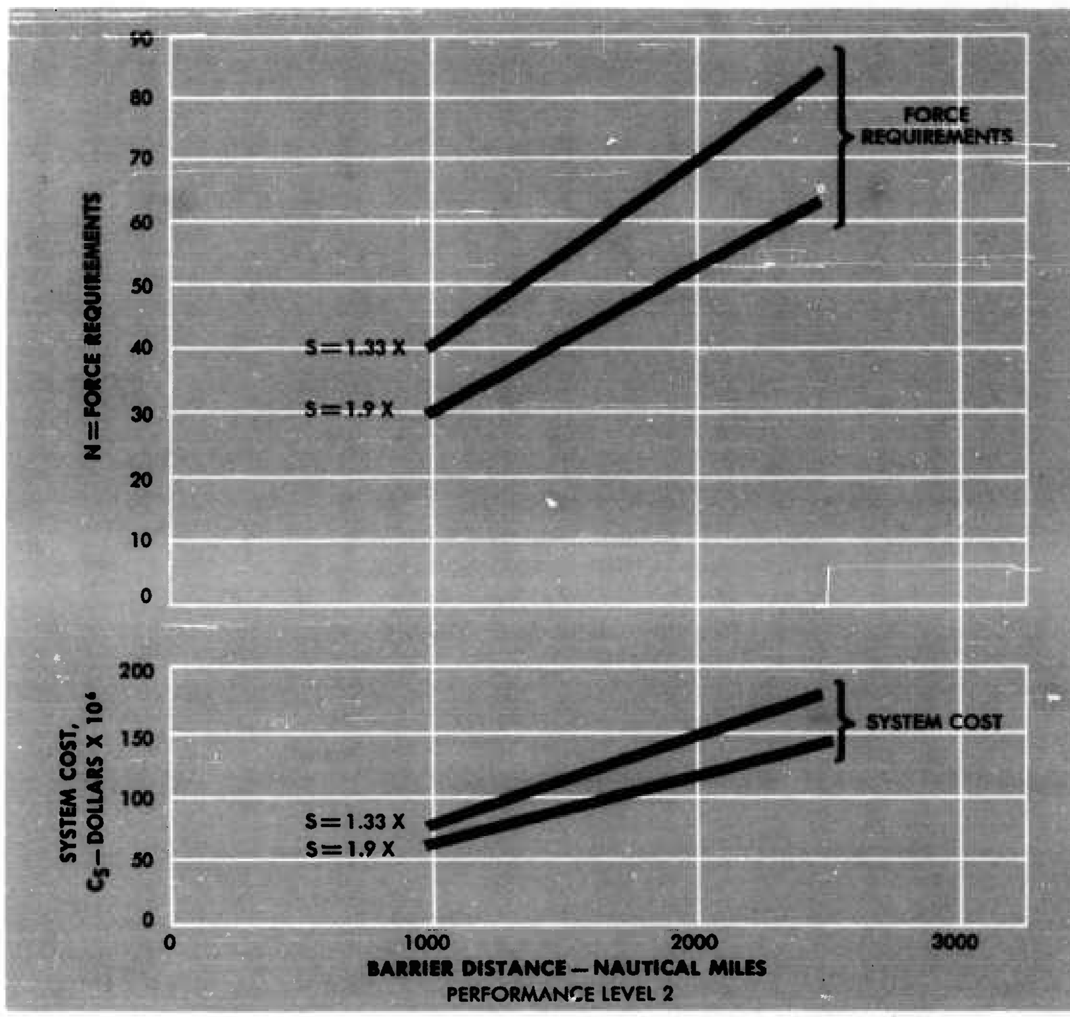


FIGURE V.24 — EFFECT ON SYSTEM COST AND FORCE REQUIREMENTS OF VARYING CONTROL CAPABILITY

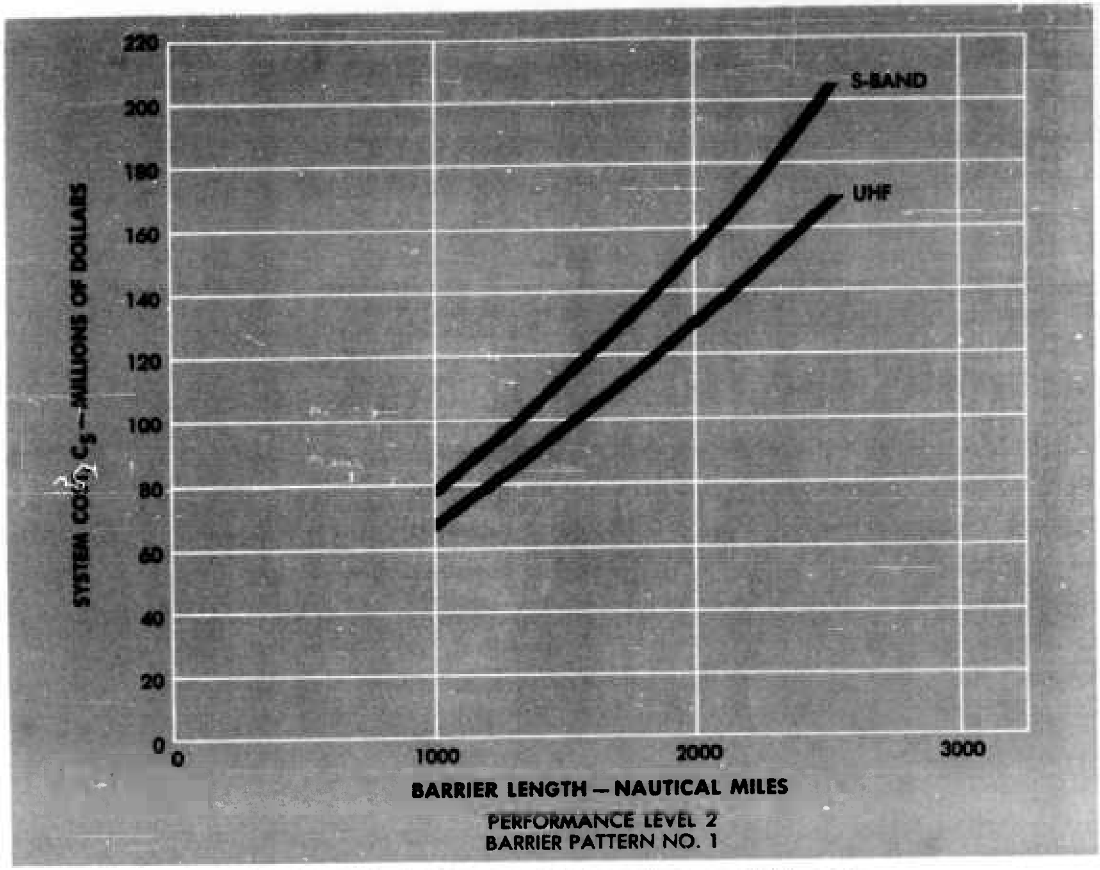


FIGURE V.25 — EFFECT OF RADAR TYPE ON SYSTEM COST

EFFECT OF TARGET SIZE ON SYSTEM COST

ANTENNA SIZE	SPACING N. MI.	N	SYSTEM COST 1m² TARGET	SYSTEM COST 7m² TARGET	PER CENT INCREASE
7.2 x 30	109	185	341.6	137.4	248.6
6 x 25	99	204	363.4	152.6	238.1
4 x 17.5	82	243	380.0	174.8	217.7

FIGURE V.26

Factors Affecting System Cost

Barrier Pattern

A comparison of the two DEW & C barrier patterns 1 and 5 reveals that barrier pattern 1 is always less expensive than barrier 5. This is shown in Figure V.27 for all barrier distances and a performance level 1. The system cost for barrier 5 rises to phenomenal proportions beyond a barrier distance of 2000 miles although at the lowest barrier distance of 1000 miles, the two barrier patterns have nearly the same system cost. This is mainly due to the fact that as the barrier distance decreases, so also does the airplane range requirement. Therefore, airplane size is reduced and airplane system cost drops. As the airplane size reduces, the influence of base cost becomes much more noticeable and tends to equalize the system cost difference between the two barriers at the low barrier distances.

Aircraft Range

In several of the DEW barrier patterns increased range in an aircraft

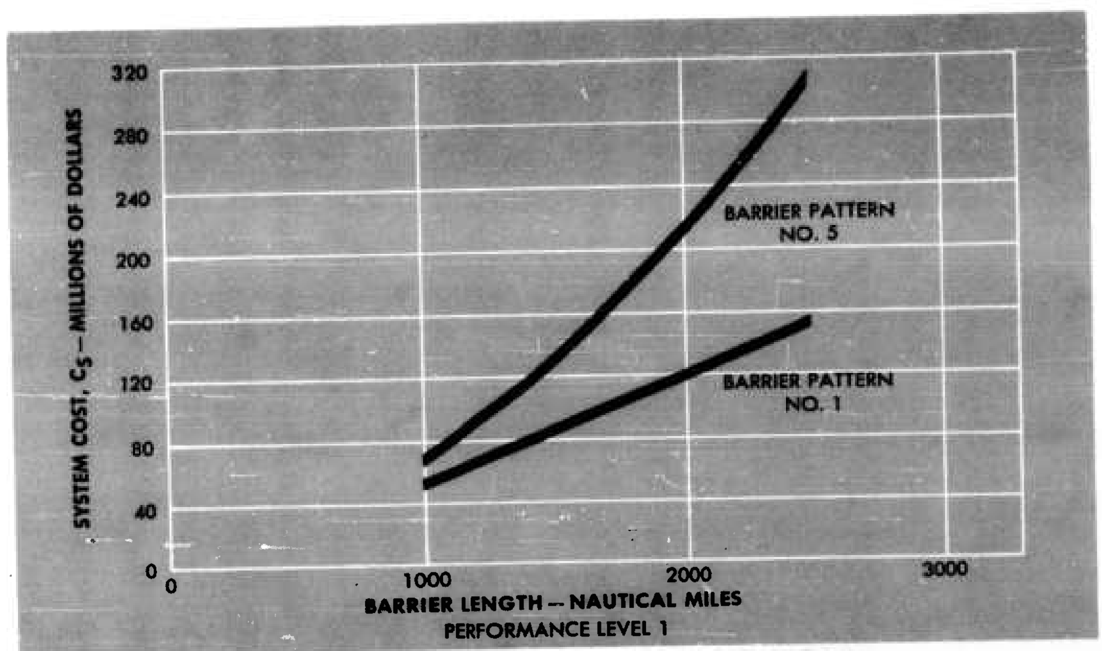


FIGURE V.27 — EFFECT OF BARRIER LENGTH AND PATTERN ON SYSTEM COSTS

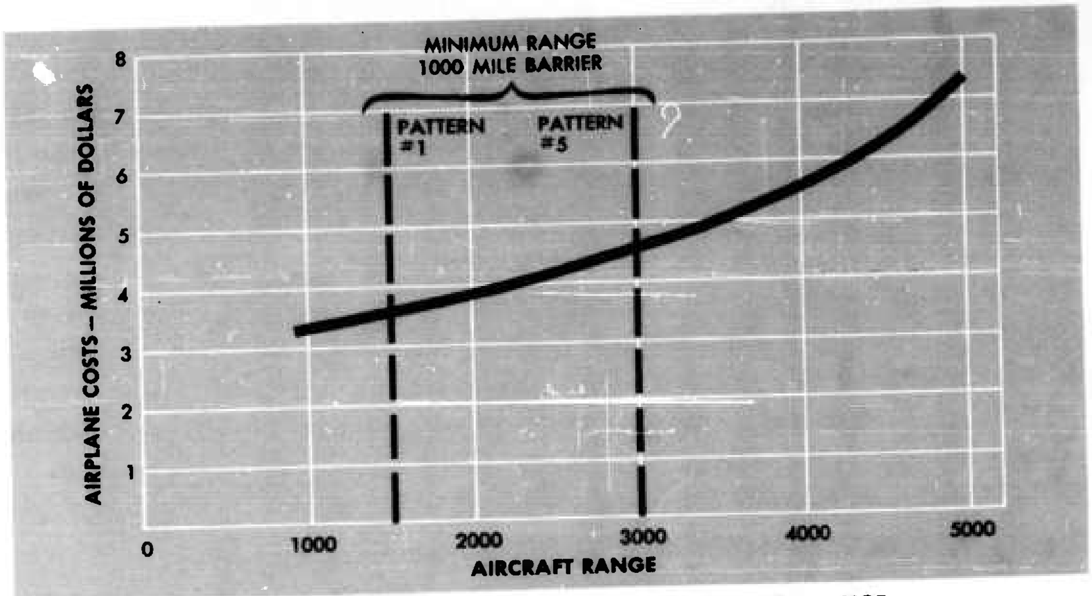


FIGURE V.28 — VARIATION OF AIRCRAFT COSTS WITH RANGE

resulted in a less costly system since the methods of employment take advantage of range. In the DEW & C barriers, the range requirement of the aircraft is dictated only by the length of the path the aircraft must fly. Increased range in the aircraft only results in higher system cost because the force requirements are not affected by increased range.

This added cost of increased range explains the sharp rise in costs of barrier 5. For a 2500-mile barrier of this pattern, the aircraft must have a range capability of nearly 6000 miles, as compared to a requirement for 3000 miles range in a pattern 1 barrier.

Figure V.28 is typical of the increase in airplane cost as the range of the aircraft increases. The dotted lines indicate the minimum range required to fly a 1000-mile pattern 1 or pattern 5 barrier.

Miscellaneous Factors

The effects of altitude, utilization, navigation, communications, use of burst speed or missiles for defense, and the use of high energy fuels are similar in nature to those discussed in the DEW section. The quantitative values are different but the general effects are the same.

CHARACTERISTICS OF OPTIMUM DEW AND C SYSTEM

RADAR PERFORMANCE LEVEL 1

BARRIER LENGTH	1000	1500	2000	2500
BARRIER PATTERN	1	1	1	1
TAKE-OFF WT. (lbs.)	90,000	90,000	110,000	110,000
MILITARY LOAD (lbs.)	28,000	78,000	28,000	28,000
RADOME SIZE (ft.)	6.3 x 31.5	6.3 x 31.5	6.3 x 31.5	6.3 x 31.5
RANGE (n. mi.)	2,110	2,110	3,220	3,220
ENDURANCE (hrs.)	11.1	11.1	15.1	15.1
VELOCITY (kts.)	200	200	225	225
ASPECT RATIO	12	12	14	14
WING LOADING (lb/ft.^{2})	30	30	40	40
NUMBER OF AIRPLANES	37	51	64	78
AIRPLANE SYSTEM COST (millions of dollars)	1.29	1.29	1.44	1.44
SYSTEM COST (millions of dollars)	75.9	102.1	137.1	165.6

RADAR PERFORMANCE LEVEL 2

BARRIER LENGTH	1000	1500	2000	2500
BARRIER PATTERN	1	1	1	1
TAKE-OFF WT. (lbs.)	90,000	110,000	110,000	130,000
MILITARY LOAD (lbs.)	30,000	30,000	30,000	30,000
RADOME SIZE (ft.)	7.5 x 37.5	7.5 x 37.5	7.5 x 37.5	7.5 x 37.5
RANGE (n. mi.)	1,710	2,560	2,560	3,330
ENDURANCE (hrs.)	9.0	13.5	13.5	15.6
VELOCITY (kts.)	200	200	200	225
ASPECT RATIO	12	12	12	12
WING LOADING (lb/ft.^{2})	30	30	30	30
NUMBER OF AIRPLANES	40	55	70	85
AIRPLANE SYSTEM COST (millions of dollars)	1.32	1.47	1.47	1.63
SYSTEM COST (millions of dollars)	82.7	120.4	151.4	197.6

FIGURE V.29

Selection of the Optimum DEW & C Airplane System

The optimum airplane systems for the DEW & C mission are shown in Figure V.29. This Table shows the airplane characteristics, barrier type, quantity, and costs for various barrier lengths. The final selection of the optimum DEW & C airplane for any one of the barriers that might be flown is straightforward. Range of the aircraft has no effect on the force requirements, and thus the airplane is selected that is optimum for the longest barrier that must be flown. The selection of any airplane for a shorter length barrier means that this airplane has inadequate range to fly the longer barriers. With this rigid limitation on the selection, the characteristics of the optimum airplanes for the two different performance levels are extracted from Figure V.29 and shown in Figure V.30.

COMPARISON OF OPTIMUM DEW AND DEW & C SYSTEMS

This section discusses the effect of using a DEW & C airplane in a DEW barrier. It also discusses the increase in cost to the U.S. if a control barrier is established, as compared to an early warning barrier.

Use of the Optimum DEW & C Airplane in a DEW Barrier

The DEW & C airplane carries a larger military load than the DEW air-

OPTIMUM DEW & C AIRPLANES

RADAR PERFORMANCE LEVEL	1	2
TAKE-OFF WEIGHT (lbs.)	110,000	130,000
RADOME SIZE (ft.)	6.3 x 31.5	7.5 x 37.5
SPEED (kts)	225	225
ALTITUDE (ft.)	35,000	35,000
MILITARY LOAD (lbs.)	28,000	30,000
ASPECT RATIO	14	12
WING LOADING (lb/ft^2)	40	30
RANGE (n. mi.)	3,220	3,330
ENDURANCE (hrs.)	15.1	15.6
AIRPLANE SYSTEM COST (millions of dollars)	1.44	1.63

FIGURE V.30

USE OF DEW AND C AIRPLANE IN DEW BARRIER					
DESIGN LEVEL	LEVEL OBTAINED	COST OF SYSTEM USING DEW	COST USING DEW & C (millions of dollars)	COST DIFFERENCE	PERCENT DIFFERENCE
2	2	132.3	149.0	16.7	12.5
1	1	117.6	131.1	13.5	11.2
1	2	147.6	161.0	13.4	9.0
2	1	132.3	149.0	16.7	12.5

FIGURE V.31

plane, and therefore is more expensive. In this respect it is less than optimum when used in a DEW barrier operation.

To determine the effect of using a DEW & C airplane in the DEW barrier, calculations were made for a barrier network of 1500 and 2500 miles, assuming the two different levels of radar performance and the use of barrier 8 for the 1500-mile barrier and barrier 4 for the 2500-mile barrier. Figure V.31 summarizes the result of this calculation.

It is seen that the penalty paid for using the DEW & C airplane in the DEW barrier is approximately 8 to 12 per cent.

Cost of Adding Control to an Airplane Barrier

In order to establish an airplane barrier with a control capability three major factors add to the cost. These are (1) the increased size of the airplane to carry the larger military load, (2) the larger number of airplanes required because of decreased spacing to insure control overlap and (3) the larger number of airplanes to permit establishment of the double line to obtain the necessary depth.

Figure V.32 shows in bar chart form the comparative costs for warning and for warning and control barriers. This figure is calculated for a network of barriers using the optimum airplane, for each performance level.

RECAPITULATION

This chapter has examined a number of factors and has indicated their influence on the selection of optimum airplane systems. A brief recapitulation is in order to re-emphasize the important points of the chapter.

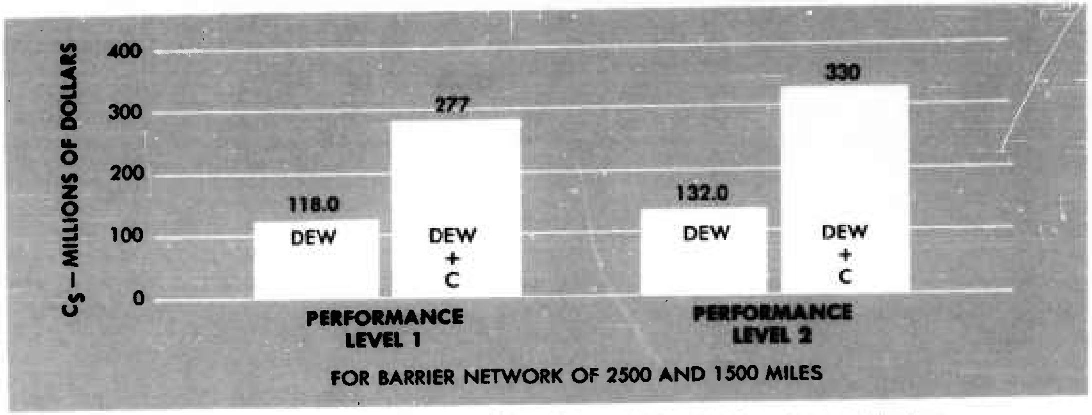


FIGURE V.32 — COMPARISON OF SYSTEM COST FOR DEW AND DEW & C

The optimum DEW airplane is a compromise between radar and airplane characteristics and performance tactics. With these taken into account, the optimum airplane cruises at 35,000 feet, carries a 6 x 25 foot antenna, and is equipped with a UHF radar. Each of the barriers examined has an optimum design airplane. After these optimum design airplanes were determined, they were examined in a network of barriers and the airplane finally selected was the one which could fly any of the barriers considered without severe penalties. In this case, the selected airplane can fly the given barriers with penalties of only five per cent or less. It must be noted, however, that airplane performance and barrier pattern must be carefully matched.

The selection of the DEW & C airplane is less complicated than the DEW airplane, since force requirements are not functions of the range of the aircraft. The airplane is selected that has the range necessary to fly the longest barrier considered. This airplane carries the 6 x 25 foot antenna in the 6.3 x 31.5 foot radome, cruises at 35,000 feet and has a range of 3220 miles.

Since there are advantages to be gained by selection of a single aircraft, the penalties paid for using the DEW & C airplane in a DEW system were determined. These penalties are from 8 to 12 per cent and when the factors of logistics, flexibility and producibility are considered, the selection of the early warning airplane with a control capability is indicated.

The design of the aircraft should be based on a moderately optimistic performance level even if there is only a limited probability of obtaining this performance level.

CHAPTER VI
SELECTION OF OPTIMUM HELICOPTER SYSTEMS

INTRODUCTION

The helicopter is the second of the vehicles examined for application in the DEW barrier operation. It will take off from a basing ship, will rise nearly vertically, hover at altitude as long as its endurance permits, and then descend to the basing ship. The helicopter must carry radar and other equipment capable of accomplishing the DEW or the DEW & C mission.

As established in earlier chapters, the measure of effectiveness used in this analysis is the highest level of protection obtainable within the limits of a defined early warning budget. The factors which enter into the measure of effectiveness for helicopter operation, are:

[HELICOPTER BARRIER SYSTEM COST] = [HELICOPTER SYSTEM COST] + [SHORE BASE COST] + [SHIP COST] + [FLIGHT PERSONNEL COST] + [MILITARY LOAD COST]

The helicopter system cost is composed of the cost of the helicopter, helicopter maintenance cost, and fuel cost.

Two types of sea base are assumed: the CVE-55 class carrier and the converted merchant vessel. This leads to variations in the analytical form of the measure of effectiveness. The generalized measure now can be expressed in more specific terms, as follows:

For DEW

$$C_S = C_{HS} + \begin{matrix} C_{MV} \\ \text{or} \\ C_{CVE} \end{matrix} + C_{IFP} + C_{ML}$$

For DEW & C

$$C_S = C_{HS} + C_{CVE} + C_{IFP} + C_{ML}$$

where

C_S = barrier system annual cost

C_{HS} = cost of all helicopters

C_B = equivalent shore base cost

C_{MV} = cost of converted liberty ships

C_{CVE} = cost of CVE's

C_{IFP} = cost for flight personnel

C_{ML} = cost of military load

Each of the terms in the measure of effectiveness can be expressed as a function of D, the length of the barrier. Therefore, calculations are necessary for only one barrier leggth which has been taken as 1000 miles.

THE PARAMETRIC ANALYSIS

The parametric analysis is designed to provide data on many thousands of possible helicopter and radar combinations. The equations relating to helicopter performance have been derived by Bell Aircraft Corporation and are explained in Reference 34.

The factors of the problem are shown diagrammatically in Figure VI.I and a typical combination is shown. Selections of radar antenna size, performance levels, barrier spacing, and altitude are based mainly on the radar performance characteristics discussed in Chapter II. In addition, large S-band antennas are examined on the basis that MTI at S-band might be effective from a hovering vehicle.

Helicopter Characteristics

Of the many possible combinations which could be generated by application of the parametric analysis, a large number are marginal or impractical, and therefore can be discarded. Those remaining for analysis still compromise a wide spread of capability and, at the same time, are a manageable quantity. The following paragraphs discuss a few of the more

34. J. F. H. Bertucci and R. W. Allen. *Early Warning Helicopter Parametric Analysis*. Lockheed Memorandum Report 7091, Military Operations Research Division, Lockheed Aircraft Corporation, 15 April 1955. (CONFIDENTIAL)

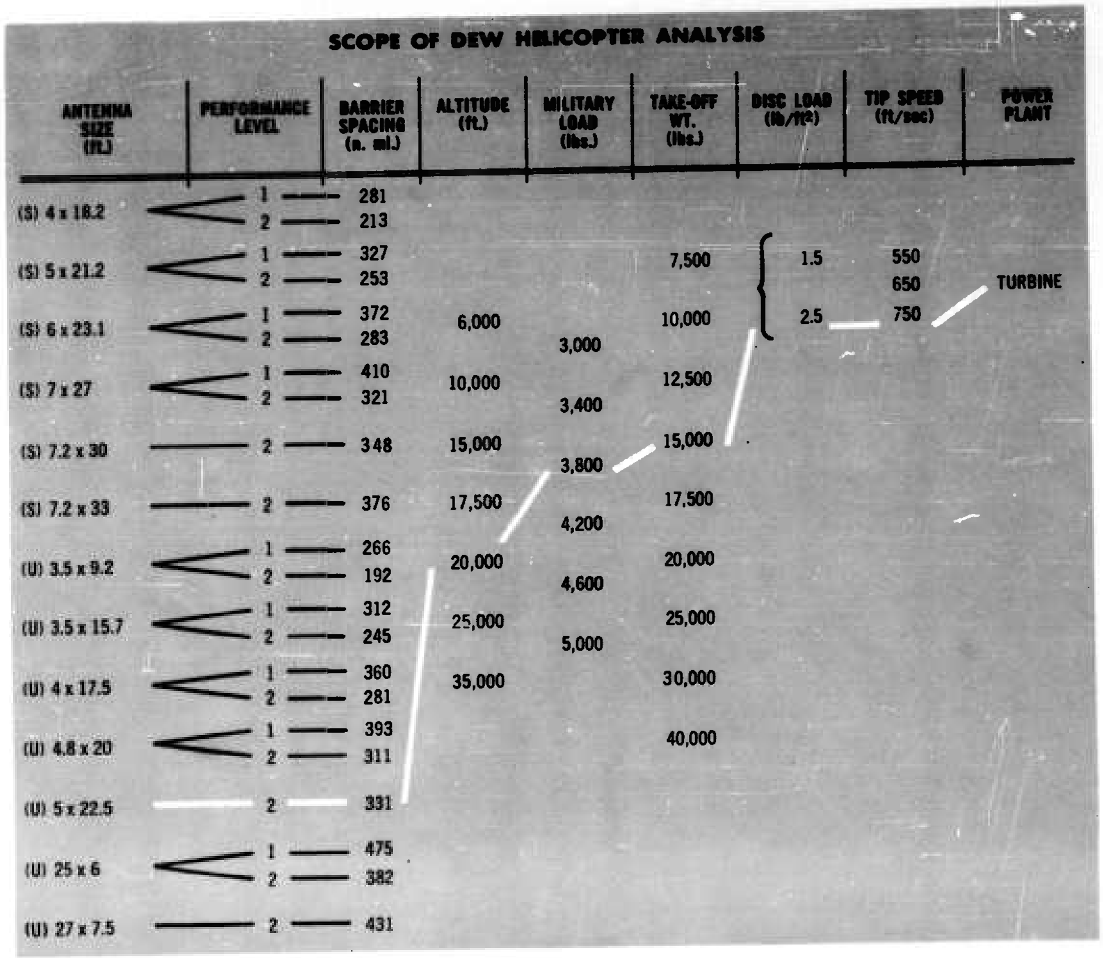


FIGURE VI.1

important characteristics and the limitations assumed.

1. The military load is composed of the crew, electronic gear and radome. The military load for the DEW helicopter ranges in value from 3,000 to 5,000 pounds and reflects the weight changes of various antenna and radome sizes. A detailed breakdown is shown in the Summary of Results of this part.

2. Design point helicopters with take-off weights from 7500 to 40,000 pounds are calculated. This is sufficient to determine an optimum helicopter configuration.

3. A preliminary analysis of many helicopter configurations reduced the optimum disc loading and tip speed combinations by requiring that the solidity ratio is always maintained at 0.025 or greater. The equations which derive the component weights are based upon an ultimate load factor of 4.5. Further design requirements are (1), the helicopter must be capable of hovering in a 50-knot wind at design altitude and (2), the turbine engine must be restricted to 75 per cent NRP at sea level. The maximum design speed is 100 knots.

4. Both reciprocating and turbine powered helicopters are examined. Preliminary results showed that, given similar operating conditions, costs of turbine powered systems were no greater, and in most cases less, than those using reciprocating power. This is partly explained by the fact that the turbine engine weighs considerably less than the reciprocating engine. Furthermore, the system costs at altitudes above 15,000 feet, for reciprocating engine power, begin to exceed costs of the turbine powered helicopter. This is because the turbine engine has better altitude performance.

5. The high altitude and large military loads associated with the DEW mission dictate helicopters of gross weights of 15,000 to 25,000 pounds. For these relatively large helicopters, a tandem rotor configuration appears to be reasonable and is used throughout.

6. The radar antenna is assumed to be enveloped in some lightweight structure, such as an inflatable type radome similar to that proposed by Goodyear Aircraft and discussed in Reference 35.

System Costs

Helicopter

The major components - structure, rotor, transmission, fuel tanks, power plant and military load, plus component spares determine helicopter costs. These components are costed by applying average cost per pound rates for similar items.

Based on a life expectancy of 5 years, an annual replacement cost of the helicopter is determined. This cost must be increased by the operating expenses of fuel, crew and maintenance to obtain the total annual cost.

Costs for crew and military load, normally included in the total helicopter cost, are examined separately to reflect variations in the DEW and

35. Goodyear Aircraft Corporation. *Design Summary Report on AEW Airship Model G2-13*. Report No. GER 5046, 30 December 1952. (CONFIDENTIAL)

DEW & C barrier types.

Crew

Helicopter crews vary in size depending on the requirements of the mission involved.

The crews are selected as follows:

Mission	Crew Size	Function
DEW	2	1 pilot, 1 co-pilot
DEW & C	5	1 height finder operator, and 1 radioman

The average monthly pay is determined for the number of officers and enlisted men required, and estimated training costs are added before establishing annual crew costs.

Military Load

Military loads include radar, communications, navigation, crew and sundry items. However, since the crew is separately costed, the crew weight is deducted from the total military load and a weighted rate per pound is determined by assigning applicable rates to each of the various types of items comprising the balance of the military load.

Sea Bases

Helicopters are based on either converted merchant vessels or CVE-55 class carriers.

In the case of the merchant vessel an acquisition cost is included, as well as costs of necessary electronic conversions, installation of a suitable landing platform, and required shops and berthing. These acquisition and conversion costs are amortized over a ten year period and are combined with operating costs for this class and the cost of reserve vessels to obtain the annual cost of maintaining a merchant vessel at sea.

To obtain a similar cost for a CVE-55 at sea, the normal operating complement was reduced to the minimum practicable crew required to service the relatively small quantity of helicopters in support of a single DEW or DEW & C station. Cost of the reduced crew was then substituted

for cost of the normal complement and an annual cost was established for maintaining a CVE-55 at sea, using available BuShips data, and assuming a life of 13.5 years.

A detailed explanation of the formulation of the cost factors is given in Reference 27.

Shore Bases

It is assumed that heavy maintenance is provided at a base established in the U.S. The cost of this type of base is derived by application of planning factors for airplane bases modified by the special requirements of the helicopter.

SUMMARY OF RESULTS - DEW BARRIERS

This section deals with the selection of optimum helicopter systems and with the effects on system costs of changes in parameters.

Radar Factors Affecting System Costs

Radar Performance Level and Antenna Size

Radar performance levels of 1 and 2 are investigated for both UHF and S-band radars. With a given antenna size, a radar performance level of 1 requires a hover at a higher altitude than is the case for a performance level of 2. Consequently, for level 1, greater spacing can be used between helicopters, thus reducing force requirements. The effect of radar performance level on system cost is shown in Figures VI.2 and VI.3 for helicopters based on merchant vessels. It will be seen that minimum costs are realized at a hovering altitude of 20,000 feet. Antenna sizes associated with each altitude are shown. The horizontal beamwidths of a number of the large-size S-band antennas are too narrow for effective radar search. Nevertheless, they are carried through in the analysis in order to provide information on system cost minimization, and also to show the effects of carrying these antennas at the higher altitudes. Since in-flight maintenance cannot be accomplished in a 2-man DEW helicopter, a radar performance level of 2 is considered more representative of expectable field performance.

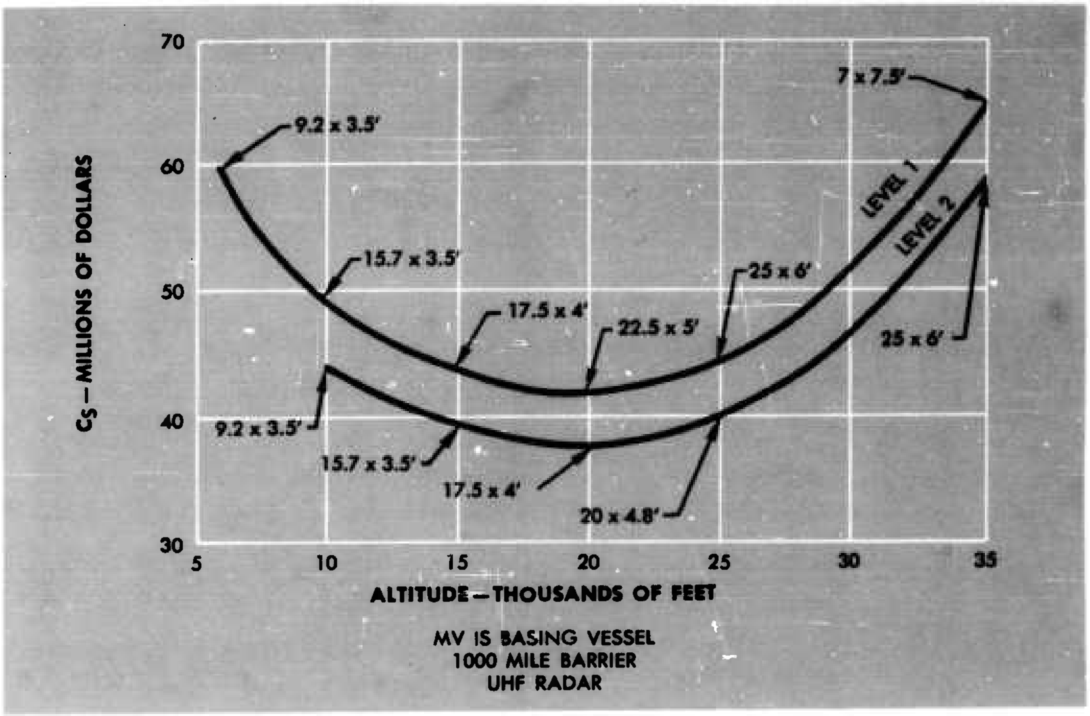


FIGURE VI.2 — EFFECT OF RADAR PERFORMANCE LEVEL

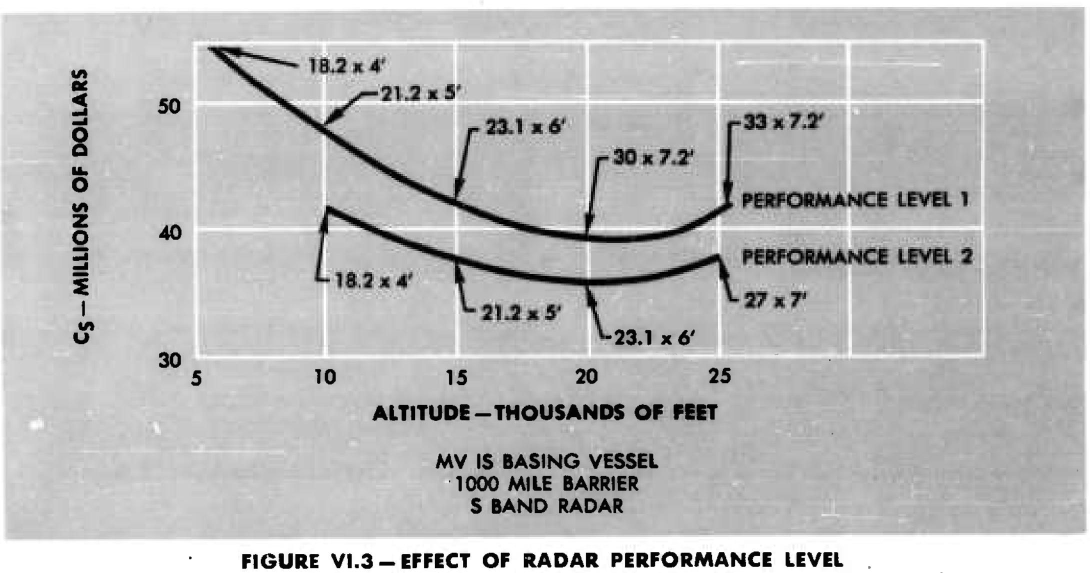


FIGURE VI.3 — EFFECT OF RADAR PERFORMANCE LEVEL

However, it is necessary to examine the penalty paid in terms of system cost when the helicopter system design is based on a radar performance level of 1, but field performance results in a level of 2. Conversely, it is necessary to learn what penalty is paid if the helicopter system is designed with a larger antenna for an expected radar performance level of 2, but field performance results in a level of 1. The results of an example are given in tabular form in Figure VI.4 for a 1000-mile barrier.

SYSTEM COST FOR UHF RADAR PERFORMANCE LEVEL ATTAINED

ANTENNA SIZE (ft.)	ALTITUDE (ft.)	DESIGN LEVEL	ATTAIN LEVEL	SPACING (mi.)	SYSTEM COST million dollars per year
4 x 17.5	20,000	1	1	360	38.3
4 x 17.5	15,000	1	2	281	49.0
5 x 22.5	20,000	2	2	331	41.7
5 x 22.5	20,000	2	1	331*	41.7

*ALTITUDE LIMITED BY HELICOPTER DESIGN

FIGURE VI.4

From the table it can be seen that, when carrying the 4 X 17.5 foot antenna at 20,000 feet, if the system is designed for a radar performance level of 1 but level 2 is attained, the system cost increases from 38.3 to 49 million dollars per year. The reduced radar performance requires that hovering altitude and helicopter spacing be decreased and force requirements increased in order to maintain the desired level of detection. When carrying the 5 X 22.5 foot antenna at 20,000 feet, if the system is designed for a radar performance level of 2 and level 2 is attained, the system cost is 41.7 million dollars per year. If level 1 is attained, advantage cannot be taken of higher altitude, greater spacing and lower force requirements, since a larger helicopter is required. The system cost remains 41.7 million dollars. The difference in system cost for designing for level 1 and attaining level 2 is 10.7 million dollars. For helicopter systems, then, the smaller penalty in system cost (3.4 million dollars) is to design for a radar performance level of 2. This reversal in design philosophy between the

airplane and the helicopter will be discussed in Chapter VIII.

Radar Type

The weight of the S-band radar system is less than that of the UHF system even though at a given altitude the S-band antenna required is larger to obtain the same level of performance.

With S-band radar, the spacing between helicopters at a given altitude is slightly greater than when using the UHF radar, resulting in fewer helicopters and ships needed for a given barrier length. This combination of reduced weight and force requirement results in a lower system cost when using the S-band radar. The effect of radar type on system cost is illustrated in Figure VI. 5.

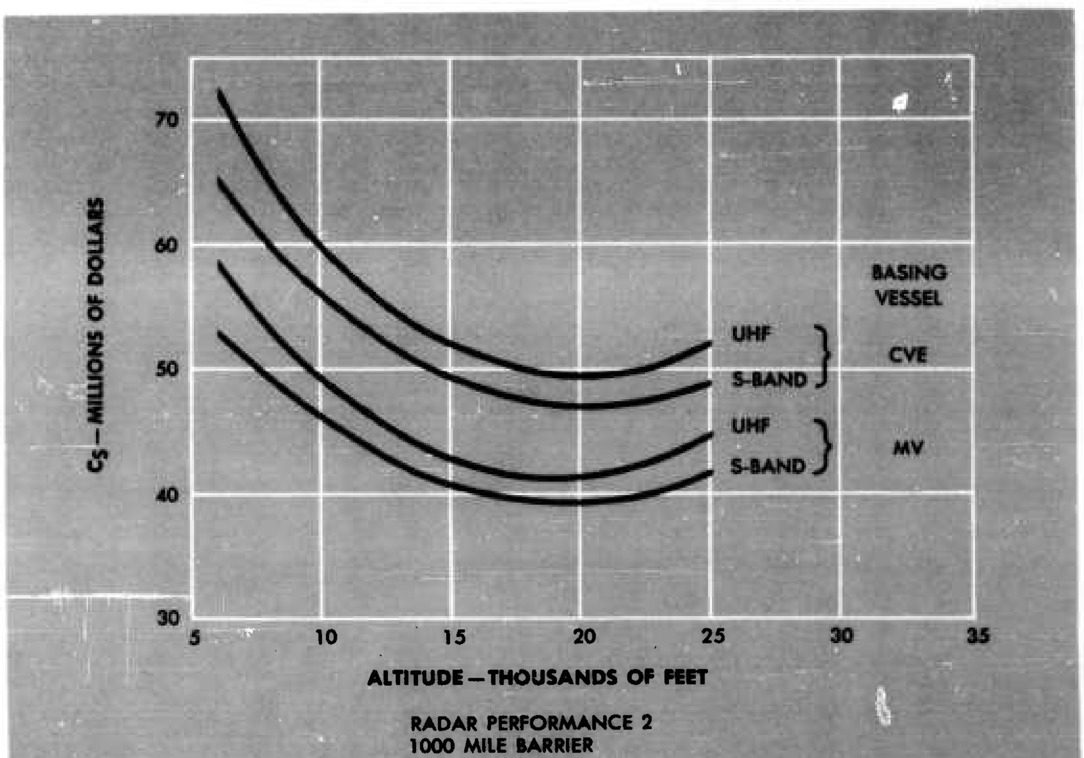


FIGURE VI.5 — EFFECT OF RADAR TYPE

Operator Factor

The spacings associated with the several antenna sizes used in the parametric analysis are based on an assumed operator factor of 0.1. If an operator factor of 0.05 is used, the system cost increases by approximately 10 per cent. A few examples are given in Figure VI.6. If an operator factor of .5 is assumed, a system cost can be decreased by approximately 10 per cent.

INCREASE IN SYSTEM COST WITH LOWER OPERATOR FACTOR (RADAR PERFORMANCE LEVEL 2)

ANTENNA SIZE (ft.)	FLIGHT ALTITUDE (ft.)	SPACING (n. mi.)	OPERATOR FACTOR	SYSTEM COST, C_S (millions of dollars)	PER CENT INCREASE
UHF 4 x 17.5	15,000	281	0.1	44.4	11.3
	15,000	252	0.05	49.5	
6 x 25	25,000	360	0.1	45.5	11.0
	25,000	324	0.05	50.5	
S-BAND 7.2 x 30	20,000	348	0.1	39.7	10.1
	20,000	316	0.05	43.7	

FIGURE VI.6

Target Reflecting Area

Helicopter spacings used in the analysis provide a cumulative probability of detection of 0.9 against a 7 square meter target penetrating the barrier at any altitude from 500 to approximately 80,000 feet. To provide the same level of detection against a 1 square meter target, the spacing between helicopters must be reduced and this increases system cost. The results of an example for UHF radar are given in the Table of Figure VI.7. However, if the same spacing is maintained, the system cost remains the same, but the probability of detection decreases. This is also shown in Figure VI.7.

INCREASE IN SYSTEM COST WITH DECREASE IN TARGET SIZE
(UHF RADAR-PERFORMANCE LEVEL 2)

ANTENNA SIZE (ft.)	FLIGHT ALTITUDE (ft.)	SPACING (n. mi.)	TARGET SIZE (sq. meters)	PROBABILITY OF DETECTION	SYSTEM COST (millions dollars)	PER CENT INCREASE
6 x 25	25,000	360	7	0.9	45.5	—
6 x 25	25,000	141	1	0.9	115.3	254
6 x 25	25,000	360	1	0.4	45.5	—

FIGURE VI.7

Factors Affecting System Cost

Altitude

Figure VI.5 shows that system cost is a function of helicopter hovering altitude. System cost decreases with an increase in altitude, minimizes at 20,000 feet, and increases with a further increase in altitude. There are several factors which contribute to this result. For example, as the altitude increases, the number of helicopters and ships required decreases due to increased spacing between vehicles. However, at altitudes above 20,000 feet the gross weight of the helicopter increases rather rapidly, thus increasing the helicopter system cost. This is a primary effect of altitude on system cost. Secondary effects of an increase in altitude are, increased time to climb to and descend from altitude, and the decrease in endurance of the helicopter. Factors which affect the system cost at altitudes above 20,000 feet are given in the Table of Figure VI.8.

Type of Basing Vessel

The system cost for DEW barriers is lower when helicopters are based on the converted merchant vessel, since the capital and annual operating costs for the merchant vessel are less than for the CVE-55. The effect of change of basing vessel is shown in Figure VI.9.

FACTORS AFFECTING SYSTEM COST AT HIGH ALTITUDES FOR 1000-MILE BARRIER

		UHF SYSTEM			S-BAND	
ALTITUDE (ft.)		20,000	25,000	35,000	20,000	25,000
MILITARY LOAD (lbs.)		3,800	4,600	4,600	3,800	4,200
GROSS WEIGHT (lbs.)		15,000	20,000	40,000	15,000	20,000
TIME TO CLIMB AND DESCEND (min.)		32	37	52	32	37
TIME ON STATION (hrs.)		1.6	1.4	1.0	1.6	1.6
NO. HELICOPTERS IN THE SYSTEM		58	54	57	55	53
MILLIONS OF DOLLARS	C_{HS}	10.9	15.3	37.3	10.3	13.9
	C_B	15.4	15.3	15.5	14.6	14.2
	C_{MV}	11.8	10.6	9.0	11.2	10.3
	C_{IFP}	1.3	1.4	1.4	1.3	1.3
	C_{ML}	2.3	2.9	2.9	2.2	2.4
	C_S	41.7	45.5	66.1	39.6	42.1

(RADAR PERFORMANCE LEVEL 2)
FOR DEFINITIONS OF THESE TERMS, SEE GLOSSARY.

FIGURE VI.8

Barrier Length

As indicated earlier, the system cost increases in direct proportion to the barrier length. Figure VI.9 shows system cost versus barrier length. For the UHF-helicopter-merchant vessel combination, the system cost increases from 41.7 million dollars per year for the 1000-mile barrier to 104.3 million dollars per year for the 2500-mile barrier.

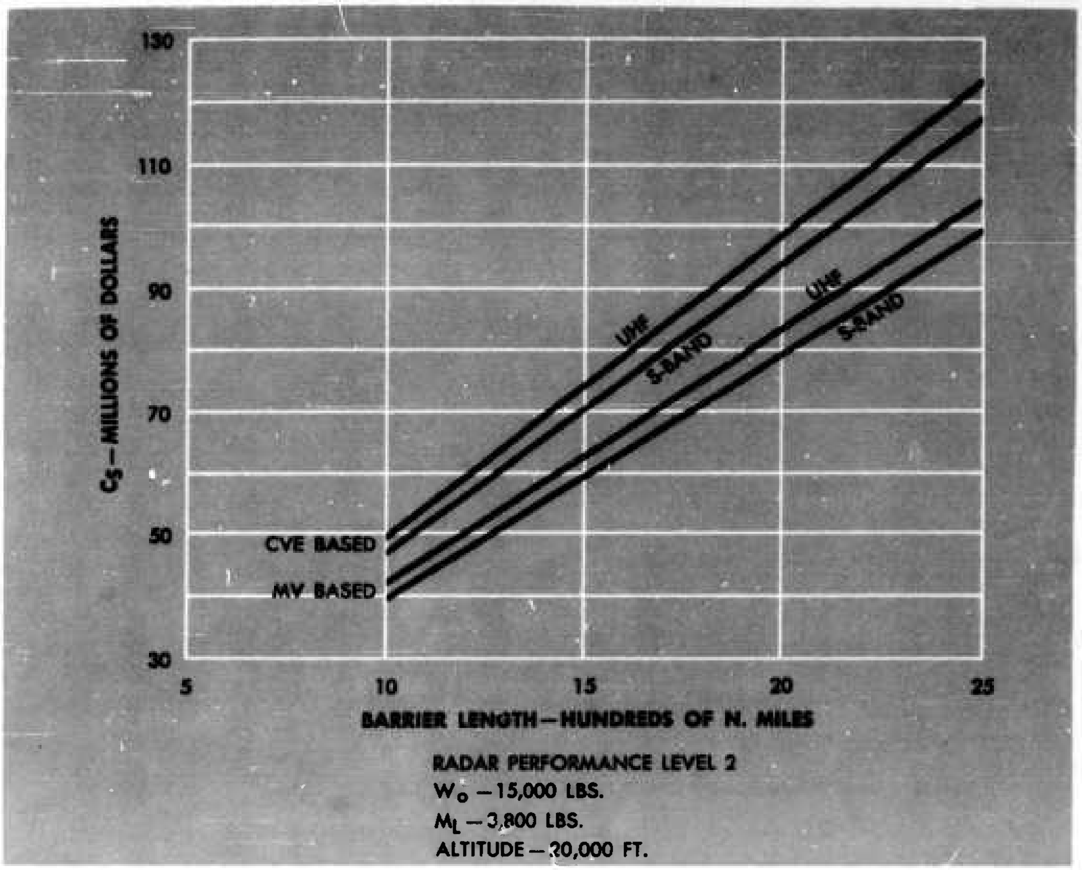


FIGURE VI.9 — SYSTEM COST VS. BARRIER LENGTH

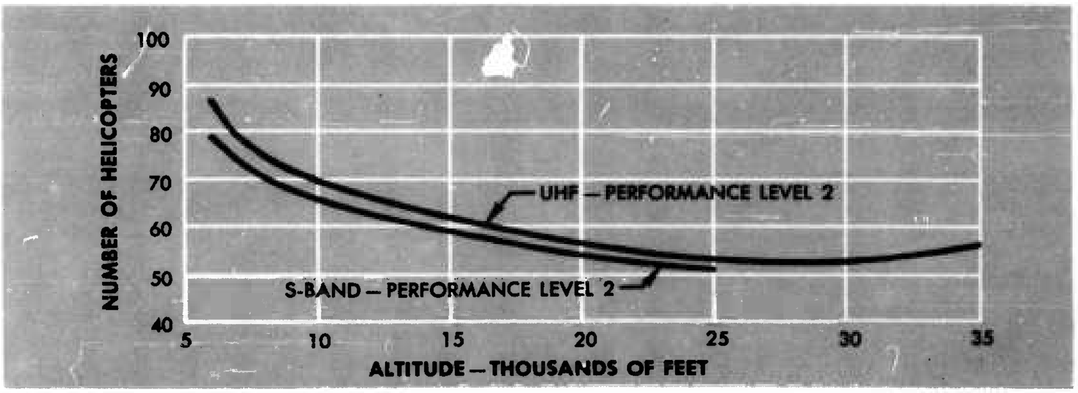


FIGURE VI.10 — NUMBER OF HELICOPTERS NEEDED FOR A 1000 MILE BARRIER

Number of Helicopters

The number of helicopters needed to maintain a round-the-clock barrier operation is a function of barrier length, spacing, and utilization. Figure VI. 10 shows the number of helicopters needed for a 1000-mile barrier as a function of altitude.

Utilization

The figure assumed for helicopter utilization in a previous study (see Reference 30) was 45 hours, of which 26 hours a month were spent at sea in productive anti-submarine work. This study assumes a squadron utilization of 75 flying hours per month per helicopter and an average operational utilization of 45 hours spent on the line in productive DEW work. This higher figure appears to be justified because helicopters designed for DEW operation are subject to less stringent operational requirements. In order to examine the effect on system cost for other utilizations, a plot of system cost versus operational utilization per month is shown in Figure VI. 11 for a 15,000 pound helicopter carrying a military load of 3800 pounds at 20,000 feet. For a utilization of less than 45 hours, the system cost increases rapidly.

Time on Station

Figure VI. 12 shows system cost versus helicopter time on station. System cost insensitive to helicopter time on station of 1 to 3 hours for a hovering altitude of 15,000 feet; 1 to 2.5 hours for an altitude of 20,000 feet and 1 to 2 hours for an altitude of 25,000 feet. The variation in system cost is approximately 5 per cent for the helicopters operating within the limits shown.

Military Load

System cost increases as military load increases for any hovering altitude, Figures VI. 13 and VI. 14 show the effect on system cost of changes in military load. For the helicopter which hovers at 20,000 feet, the effect on system cost for a range of military loads from 3400 to 5000 pounds is to

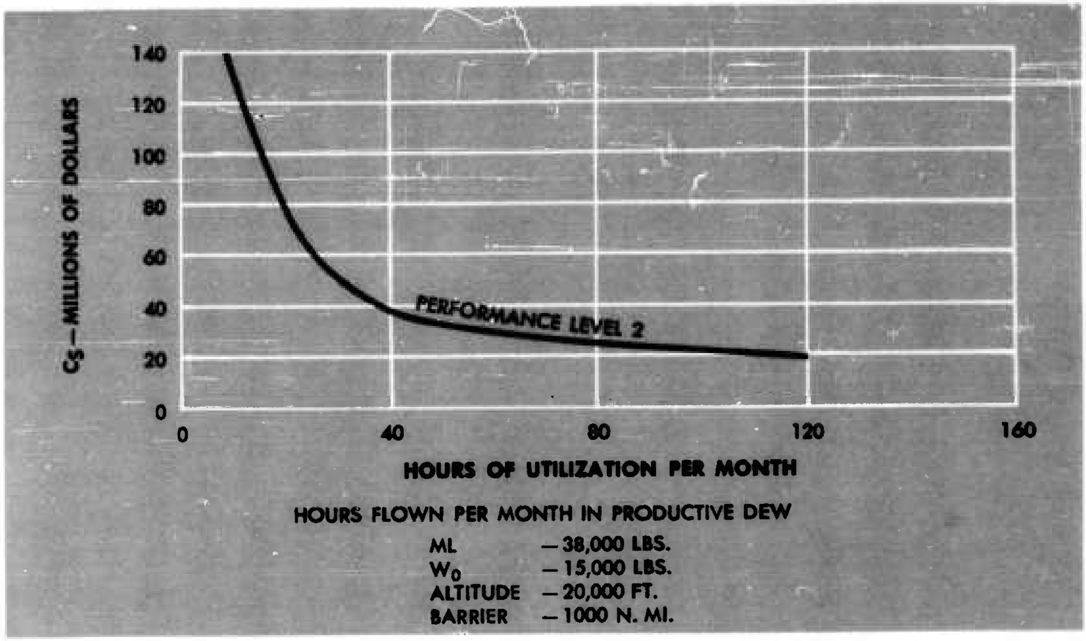


FIGURE VI.11 — SYSTEM COST VS. HOURS UTILIZATION PER MONTH

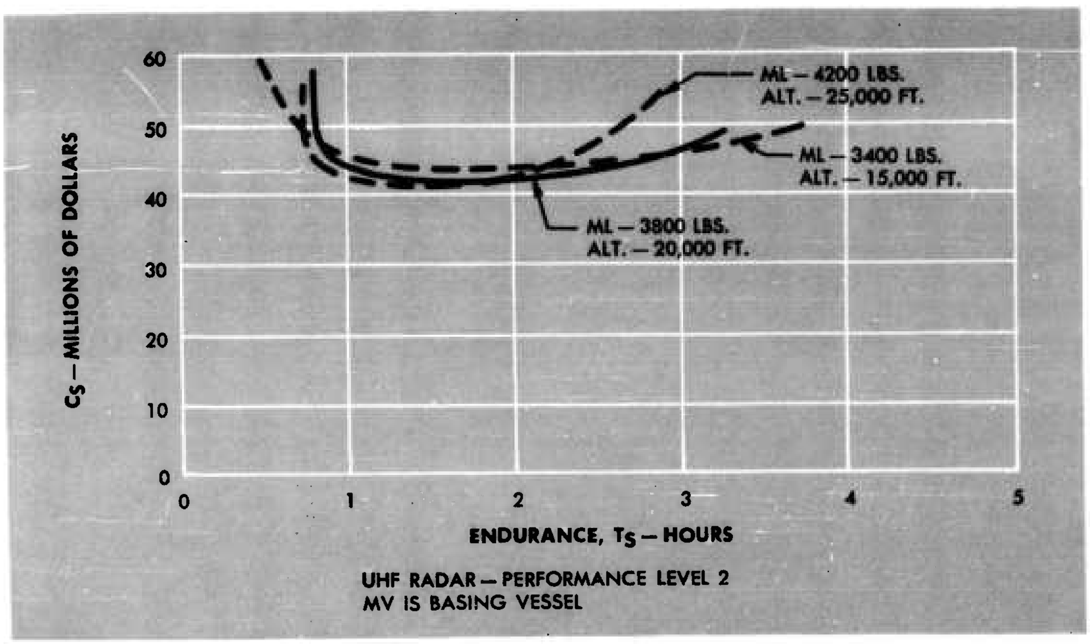


FIGURE VI.12 — SYSTEM COST VS. ENDURANCE

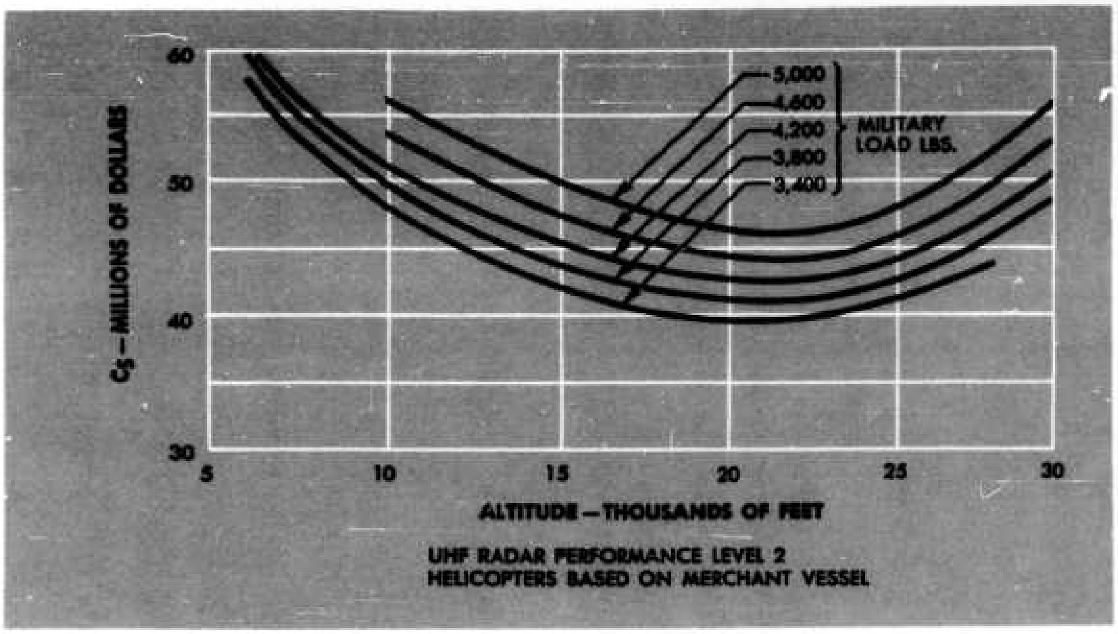


FIGURE VI.13—SYSTEM COST VS. ALTITUDE

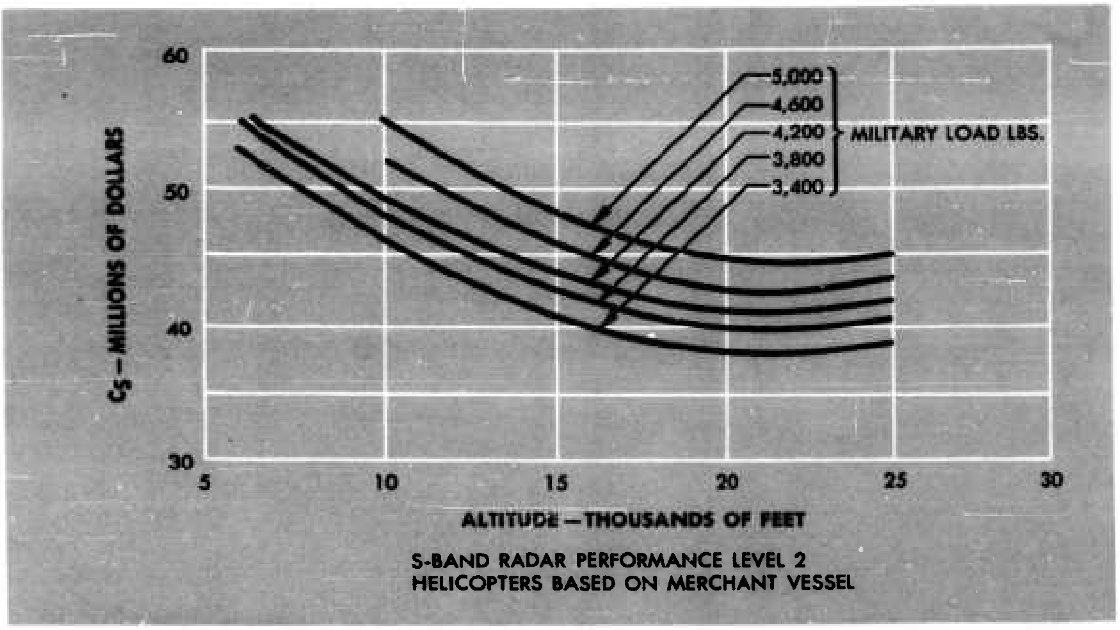


FIGURE VI.14—SYSTEM COST VS. ALTITUDE

increase the cost from 38.0 to 44.5 million dollars or approximately 17.0 per cent.

However, an estimate of the actual range of the military loads to be carried by the helicopter is less than this 2000-pound range spread. This is shown in Figure VI.15. It is seen that the spread of the actual military loads is 550 pounds for UHF and 720 pounds for S-band.

For a performance level of 2 in the UHF system, the parametric analysis indicates that minimum system cost is realized with a helicopter hovering at 20,000 feet and carrying a 5 X 22.5 antenna. From Figure VI.15 the military load associated with the 5 X 22.5 antenna is 3890 pounds.

From Figure VI.13 the system cost can be obtained by interpolation for this military load and is approximately $41.7 million per year.

For the S-band system, the antenna size is 7.2 X 30 feet, and from Figure VI.15, the military load associated with this antenna is 3665 pounds. By interpolation for this military load in Figure VI.14, the system cost is approximately $39.0 million per year.

<u>Adding Defense Armament</u>

The addition of a military load to provide a defense capability comparable to that previously discussed in Chapter V for the airplane, will increase system costs by approximately 40 per cent.

<u>Comparison of Barrier Component Costs</u>

For either the UHF or S-band radar, if identical helicopters are based on either merchant vessels or CVE-55 carriers, a comparison of the component costs shows that system cost increase is due to the increased ship cost of the CVE over the MV. The CVE capital and yearly operating costs are larger than for converted merchant vessels. Figure VI.16 compares the cost of components for a UHF radar system.

In addition, it is often suggested that the CVE and merchant ship hulls are available without cost. The change in system cost, if capital costs of the basing vessels are not charged to the system, is shown by the dotted lines in Figure VI.20.

The effect of radar type on the cost of components in a 1000-mile DEW barrier system is shown in Figure VI.17. For a given type of helicopter

ESTIMATE OF ACTUAL MILITARY LOADS

UHF SYSTEM

ANTENNA SIZE	3.5 x 9.2	3.5 x 15.7	4 x 17.5	4.8 x 20	5 x 22.5	6 x 25
FIXED EQUIP.	880	880	880	880	880	880
RADAR	1985	1985	1985	1985	1985	1985
ANTENNA	200	310	370	430	485	600
RADOME	35	75	85	110	140	170
CREW	400	400	400	400	400	400
TOTAL	3500	3650	3720	3805	3890	4035

S-BAND SYSTEM

ANTENNA SIZE	4 x 18.2	5 x 21.2	6 x 23.1	7 x 27	7.2 x 30	7.2 x 33
FIXED EQUIP.	880	880	86[illegible]	880	880	880
RADAR	1285	1285	1285	1285	1285	1285
ANTENNA	465	495	575	720	860	975
RADOME	90	120	145	195	240	295
CREW	400	400	400	400	400	400
TOTAL	3120	3180	3285	3480	3665	3835

FIGURE VI.15

based on a merchant vessel, the cost of all system components is slightly greater for UHF than for S-band systems.

Figure VI. 18 compares the effect of altitude on the cost of components in a 1000-mile barrier. For the 12,500 pound helicopter hovering at an altitude of 15,000 feet, the helicopter system and military load costs are smaller than for the 15,000-pound helicopter operating at 20,000 feet, but all other component costs are greater. This is because more helicopters ships and personnel are required for the barrier in which the helicopter operates at 15,000 feet.

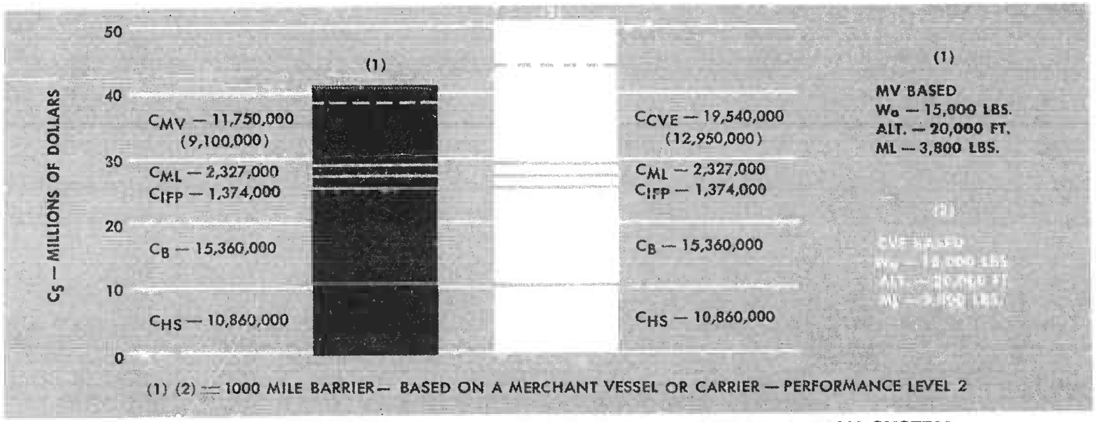


FIGURE VI.16 — COMPARISON OF COST COMPONENTS IN A DEW SYSTEM

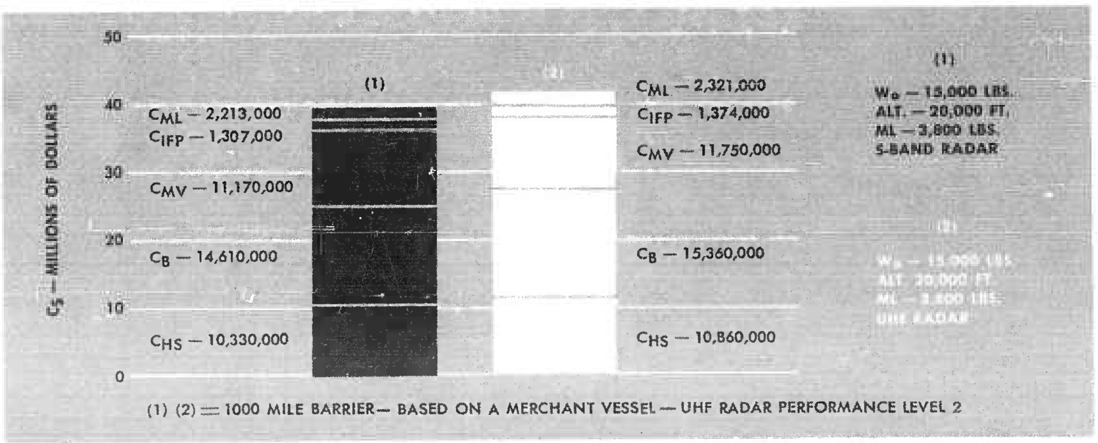


FIGURE VI.17 — EFFECT OF RADAR TYPE ON COST OF COMPONENTS IN THE DEW SYSTEM

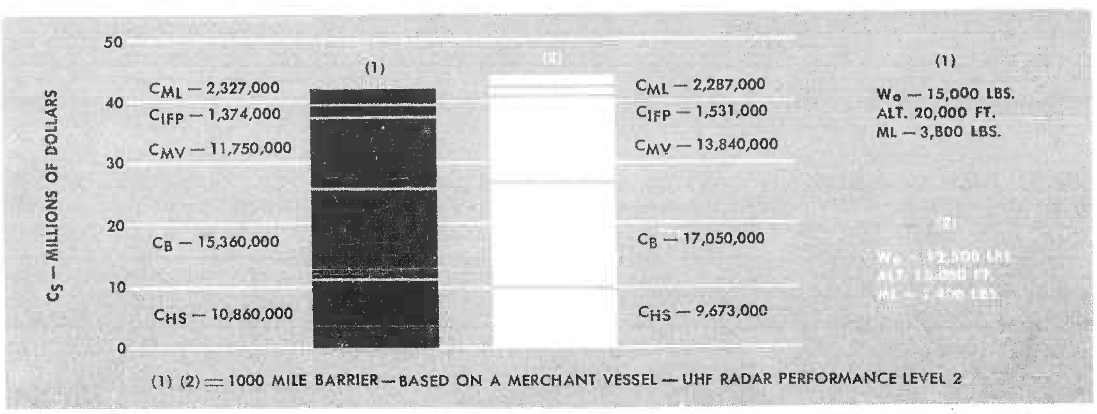


FIGURE VI.18 — EFFECT OF ALTITUDE ON COST OF COMPONENTS IN THE DEW SYSTEM

SELECTION OF THE BEST DEW SYSTEMS

Taking into consideration the factors discussed in previous sections, the characteristics of the DEW systems which provide a minimum system cost are shown in the Table of Figure VI.19. There is a difference of approximately 3 million dollars per year in the system cost, for the 1000-mile barrier, between the UHF and S-band systems.

CHARACTERISTICS OF THE OPTIMUM DEW SYSTEMS

	UHF SYSTEM	S-BAND SYSTEM
ALTITUDE (ft.)	20,000	20,000
MILITARY LOAD (lbs.)	3,890	3,665
GROSS WEIGHT (lbs.)	15,000	15,000
WEIGHT EMPTY (lbs.)	8,450	8,450
TIME TO CLIMB AND DESCEND (min.)	32	32
TIME ON STATION (hrs.)	1.6	1.8
EQUIVALENT SHAFT HORSEPOWER	2,700	2,700
DISC LOADING (lbs. sq. ft.)	2.5	2.5
TIP SPEED (ft./sec.)	750	750
ROTOR RADIUS (ft.)	32.0	32.0
FUSELAGE LENGTH (ft.)	50.0	50.0
ANTENNA SIZE (ft.)	5 x 22.5	7.2 x 30
SPACING (n. mi.)	331	348
NUMBER OF HELICOPTERS IN THE SYSTEM	58	55
COST OF HELICOPTERS (dollars)	86,000	86,000
COST OF HELICOPTER SYSTEM (millions of dollars)	10.9	10.3
SYSTEM COST (millions of dollars)	41.7	38.7

FIGURE VI.19

The UHF helicopter system is selected as an optimum DEW system since it fulfills the requirements of the measure of effectiveness. The antenna size is 5 X 22.5 feet. The horizontal beamwidth is 8 degrees, which is satisfactory for radar search. The analysis indicates that this is a 15000-pound gross weight helicopter carrying a 3890-pound military load. Hovering altitude is 20,000 feet.

The S-band helicopter carries a 7.2 X 30 foot antenna. The horizontal beamwidth is 0.85 degree which is considered to be too narrow for effective radar search. (See Chapter II) Therefore, this S-band system which provides a minimum system cost is not an optimum system since it does not provide the desired level of detection.

CHARACTERISTICS OF THE S-BAND DEW SYSTEM SELECTED

ALTITUDE (ft.)	15,000
MILITARY LOAD (lbs.)	3,300
GROSS WEIGHT (lbs.)	12,500
WEIGHT EMPTY (lbs.)	6,732
TIME TO CLIMB AND DESCEND (min.)	29.3
ENDURANCE (hrs.)	1.93
EQUIVALENT SHAFT HORSEPOWER	1903
DISC LOADING (p.s.f.)	2.5
TIP SPEED (ft./sec.)	750
ROTOR RADIUS (ft.)	29
FUSELAGE LENGTH (ft.)	46
ANTENNA SIZE (ft.)	6 x 23.1
SPACING (n. mi.)	283
NUMBER OF HELICOPTERS IN THE SYSTEM	64
COST OF HELICOPTER (dollars)	66,600
COST OF HELICOPTER SYSTEM (millions of dollars)	9.61
SYSTEM COST (millions of dollars)	41.0

FIGURE VI.19a

However, an S-band system carrying a smaller antenna can be chosen which, though not optimum, will fulfill the requirements of the measure. For example, a 12,500-pound gross weight helicopter carrying an estimated actual military load of 3285 pounds and a 6 X 23.1 antenna at an altitude of 15,000 feet is investigated. The system cost is approximately 41 million dollars, a value which can be obtained from Figure VI.15. The characteristics of this helicopter system are given in the Table of Figure VI.19a.

Therefore, the analysis provides two systems, one for UHF and one for S-band. System cost for both is approximately the same. Since either system can be selected, it is considered necessary to re-emphasize the advantages that may accrue, if UHF or longer wavelengths are used as pointed out in Chapter II.

SUMMARY OF RESULTS - DEW & C BARRIERS

This section discusses helicopter systems which have a control as well as a search capability. As for the airplane case, the amount of control has not been optimized, but an optimum helicopter is chosen with a selected amount of control.

Effects on System Cost of Radar Parameter Changes

The model for DEW & C barriers is described in Chapter IV. This model is designated as Pattern 1. Two variations of this model are investigated. The first, designated as barrier 1-a, consists of a double line of helicopters equipped with UHF radar for search and height finding. The second, designated as barrier 1-b, consists of a double line of helicopters equipped with S-band radar for search and an AN/APS-45 radar for height finding.

Antenna Size and Spacing

For barrier 1-a, the helicopters carry the 5 X 22.5 foot UHF antenna. Operational altitude is 20,000 feet. A spacing of 232 miles for control or 70 per cent of the level 2 UHF search spacing (331 miles) is used between helicopters in both lines. For barrier 1-b, the S-band antenna size selected which provides an acceptable beamwidth for search operation is 5 X 21.2 feet. Spacing between helicopters in both lines is 150 miles to provide con-

trol within the capabilities of the AN/APS-45 radar. Operational altitude is 10,000 feet. System costs for barrier 1-b are greater than for barrier 1-a.

Performance Level and Radar Type

The system cost is lower for a radar performance level 1 than for a level 2. However, as with DEW helicopter systems, a radar performance level of 2 is considered representative of expected field performance.

Because of the limitations of the height finder capabilities, system costs are higher for the S-band and AN/APS-45 combination radar systems than for the UHF radar system.

Operator Factor

Although early target detection is still important, operator alertness does not significantly affect spacing and, therefore, system costs. A change in operator factor in the DEW & C barriers is not as significant as in the DEW barriers, since spacings are reduced by significant values in order to obtain overlap for control purposes.

Factors Affecting System Cost of DEW & C Barriers

Altitude

For barrier 1-a, as for the DEW barrier, system costs minimize at 20,000 feet. For barrier 1-b, system costs rise sharply for altitudes above 10,000 feet due to large helicopter system costs resulting from additional military load, larger gross weight and the greater number of helicopters required in the system with the 150-mile spacing in both lines.

Military Load

For DEW & C barriers, a range of military loads from 5,980 to 7,900 pounds is investigated. The effects of an increase in military load are more pronounced for the DEW & C helicopter, because the increase in this region of military loads causes a marked increase in helicopter gross weight.

Miscellaneous Factors

Other factors examined in connection with the DEW & C barriers are the same as those in the DEW barrier. The general effects of barrier length, utilization and endurance are similar to those in the DEW barrier.

Comparison of Barrier Component Costs

The costs of the various components in each of the DEW & C barriers are shown in bar chart form in Figure VI.20. Although the helicopter used in barrier 1-a is larger than that required for barrier 1-b, the close spacing dictated by the height finder in barrier 1-b increases the over-all system cost by a significant amount.

Selection of the Best DEW & C System

Barrier 1-a using a helicopter with a UHF radar design based on a performance level 2, is selected as the best DEW & C system. The characteristics of the optimum helicopter system to conduct DEW & C are shown

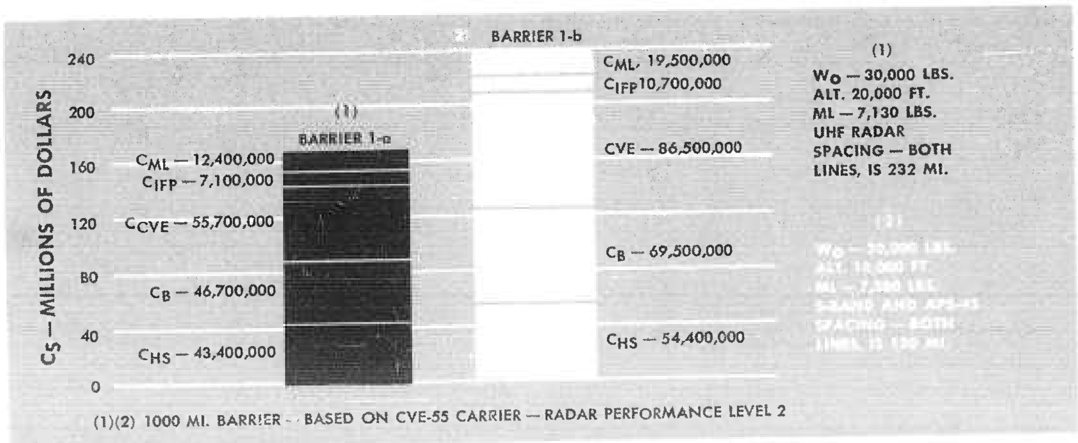


FIGURE VI.20 — COMPARISON OF COST OF COMPONENTS IN A DEW & C SYSTEM

in Figure VI.21. Lower system cost is attained with this system and is $165.3 million per year for a 1000-mile barrier.

COMPARISON OF OPTIMUM DEW AND DEW & C SYSTEMS

It is well to examine the penalty incurred in system cost if the DEW & C helicopter is used in the 1000-mile DEW barrier. The gross weight of the DEW & C helicopter is 30,000 pounds; it carries a 7130-pound military load; and it requires the employment of the CVE-55 carrier as the basing ship. The gross weight of the DEW helicopter is 15,000 pounds; it carries a 3800-pound military load; and it is based on the converted merchant vessel. Operational altitude for both is 20,000 feet.

CHARACTERISTICS OF THE OPTIMUM DEW & C SYSTEMS

ALTITUDE (ft.)	20,000
MILITARY LOAD (lbs.)	7130
GROSS WEIGHT (lbs.)	30,000
WEIGHT EMPTY (lbs.)	17,750
TIME TO CLIMB AND DESCEND (min.)	26
ENDURANCE (hrs.)	2.4
EQUIVALENT SHAFT HORSEPOWER	3585
DISC LOADING (p.s.f.)	1.5
TIP SPEED (ft./sec.)	650
ROTOR RADIUS (ft.)	58
FUSELAGE LENGTH (ft.)	90
ANTENNA SIZE (ft.)	5 x 22.5
SPACING (n. mi.)	232
NUMBER OF HELICOPTERS IN THE SYSTEM	173
COST OF HELICOPTER (dollars)	112,000
COST OF HELICOPTER SYSTEM (millions of dollars)	43.4
SYSTEM COST (millions of dollars)	165.3

HELICOPTER BASED ON CVE-55 CARRIER — UHF RADAR PERFORMANCE LEVEL 2

FIGURE VI.21

In Figure VI.22 the system cost and the cost of components of the optimum DEW helicopter system are compared to those of the optimum DEW & C helicopter system if used in the DEW barrier. The penalty or the increase in system cost is $14.3 million per year, or an increase of 34.3 per cent.

Cost of Adding Control to the Helicopter

The cost of adding control to the helicopter system is high. System cost and cost of components are compared in the bar chart of Figure VI.23. The system cost for the optimum DEW system is $41.7 million per year. The system cost for the optimum DEW & C system is $165.3 million per year. The increase in cost to provide control is $123.6 million.

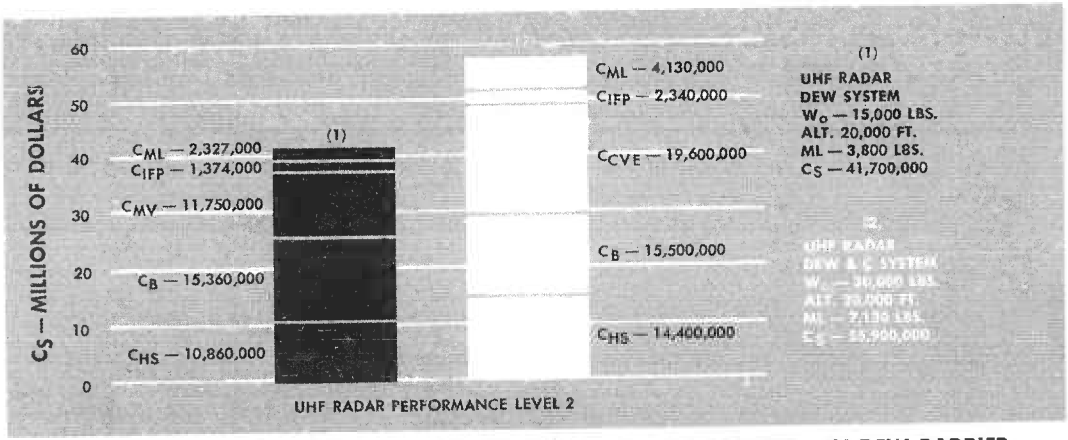


FIGURE VI.22 — EFFECT OF USING THE OPTIMUM DEW & C HELICOPTER IN DEW BARRIER

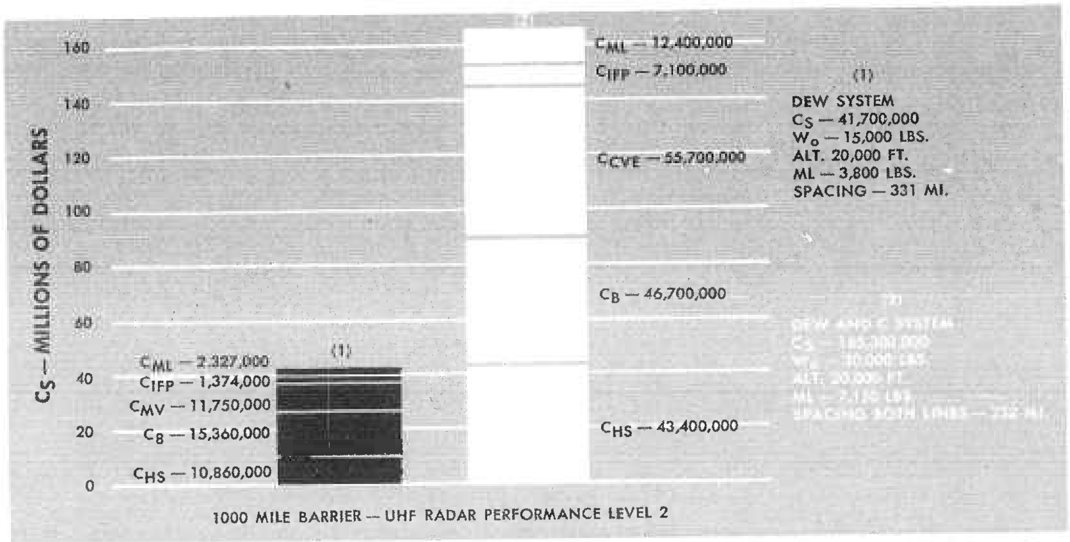


FIGURE VI.23 — COMPARISON OF COSTS FOR ADDING CONTROL TO THE HELICOPTER SYSTEM

RECAPITULATION

The important factors in selection of the optimum helicopter are discussed briefly to re-emphasize their influence.

Since the helicopter is limited in transit radius, it must operate from a sea base. Of the two sea bases considered, CVE's and converted merchantmen, it is advantageous when feasible to employ the merchantmen because

of the lower system cost. However, if a DEW & C helicopter is used, because of its large size it must be operated from a CVE. The principal contribution that these ships make to over-all system cost is that of the yearly operating expenditures for crew and supplies. The effect on system cost of not including the capital cost of basing ships is to decrease system cost by approximately 6 per cent.

As for the airplane, the design of the helicopter must be based upon certain expected radar levels. In the case of the helicopter, design should be based on an expected radar performance level 2. This is because, if radar design is based on a radar level of one, and this level is not obtained, severe penalties are incurred.

The optimum DEW helicopter hovers at an altitude of 20,000 feet and carries a UHF radar equipped with a 5 X 22.5 antenna. It has a gross weight of 15,000 pounds and can remain on station for 1.6 hours. For this hovering altitude, system cost is insensitive to helicopter time on station of from 1 to 2.5 hours. The optimum DEW & C helicopter has characteristics similar to the DEW helicopter except that it has a gross weight of 30,000 pounds and must be based on a CVE. Its time on station is 2.4 hours.

The extra military load required for the DEW & C helicopter and the fact that it must be based on the CVE greatly increases the system cost of a DEW & C barrier. Further, if this DEW & C helicopter is used in a DEW barrier, barrier system cost is increased by approximately one-third. Because of the different characteristics of the DEW and the DEW & C helicopter systems, it is not economically practical to select a single vehicle to carry out both missions.

All costs in the helicopter system are related directly to barrier length so that system cost increases in direct proportion to barrier length.

CHAPTER VII
SELECTION OF OPTIMUM AIRSHIP SYSTEM

INTRODUCTION

The barriers analyzed in this chapter for airship operations are essentially the same as those previously considered. The airship, however, has certain unique capabilities, and these are examined and presented in this chapter.

Performance capabilities of both rigid and non-rigid AEW airships have been determined by the Goodyear Aircraft Corporation under subcontract to the Lockheed Aircraft Corporation. These generalized data, together with an explanation of the methodology used, are reported in Goodyear Aircraft Corporation Report GER 6088, (Reference 36), and from the basis of the airship performance capabilities developed in this study.

Details of a parametric analysis using airships to maintain DEW and DEW & C barriers are presented in Reference 37, in which operational requirements are integrated with the airships generated. Total system costs are determined for a specified capability. The findings of that study are summarized here.

The selection of the optimum system is accomplished by application of the general measure of effectiveness, defined earlier as the cost of maintaining a barrier which provides a given level of detection. For the airship, the factors that enter into the measure of effectiveness are:

$$\left[\begin{array}{c}\text{BARRIER}\\\text{SYSTEM}\\\text{COST}\end{array}\right] = \left[\begin{array}{c}\text{AIRSHIP}\\\text{SYSTEM}\\\text{COST}\end{array}\right] + \left[\begin{array}{c}\text{BASE}\\\text{COST}\end{array}\right] + \left[\begin{array}{c}\text{FLIGHT}\\\text{PERSONNEL}\\\text{COST}\end{array}\right] + \left[\begin{array}{c}\text{MILITARY}\\\text{LOAD}\\\text{COST}\end{array}\right]$$

THE PARAMETRIC ANALYSIS

In the Goodyear study (Reference 36), both rigid and non-rigid airships were considered. The data generated showed that for any missions considered

36. Goodyear Aircraft Corporation. *Airship Parametric Analysis.* Report No. GER 6088, 1 September 1954. (CONFIDENTIAL)

37. D. W. Baxter. *Early Warning Airship Parametric Analysis.* Lockheed Memorandum Report 7092, Military Operations Research Division, Lockheed Aircraft Corporation, 15 April 1955. (CONFIDENTIAL)

in this study, the non-rigid airship is smaller than its rigid counterpart. Therefore, on the basis of cost, the choice of the non-rigid airship is clearly indicated, and only this type is analyzed in the present study.

The scope of the parametric analysis contained in Lockheed Memorandum Report MR 7092 (Reference 37) is indicated in Figure VII. 1. Military load weights of 24,000, 30,000 and 36,000 pounds are carried through this analysis to cover the range of actual loads studied. Fifty-four parametric airship configurations are examined. These airships are considered with the geographic variables of the analysis to obtain curves of the optimum airships for each situation and the numbers required for specified conditions. Final data are obtained as a function of military load to permit selection of total system cost figures associated with any specific military load.

Results are shown in terms of obtaining a certain level of detection compatible with a fixed budget. These costs are derived for several barriers, varying from 500 to 3,000 nautical miles in length. The basic patterns described in Chapter IV are investigated for these barriers and associated costs are determined.

The two basic missions, DEW only and DEW & C, generate two types of airship systems, which differ mainly in total force requirements and in the detailed make-up of the military load. Each airship system is described separately and, also, the two are compared. An additional system, DEW plus self-defense, is also examined. This is a DEW system with the addition of a height finder radar, defensive missiles, associated computers and additional personnel to operate the added equipment. The airships required for this system are larger than for either of the other two. The force requirements are identical to those required for the DEW only systems. Costs are discussed in the final portion of this section.

The mission profiles of all airships investigated are similar. Figure VII.2 illustrates a typical mission (certain modifications to this profile are considered in Reference 37). In each case, the airship departs from base, and flies to the operating area at sea level at 30 knots ground speed against a 20-knot head wind. The airship then hovers on station for its design time, monitoring the assigned area, and returns to base.

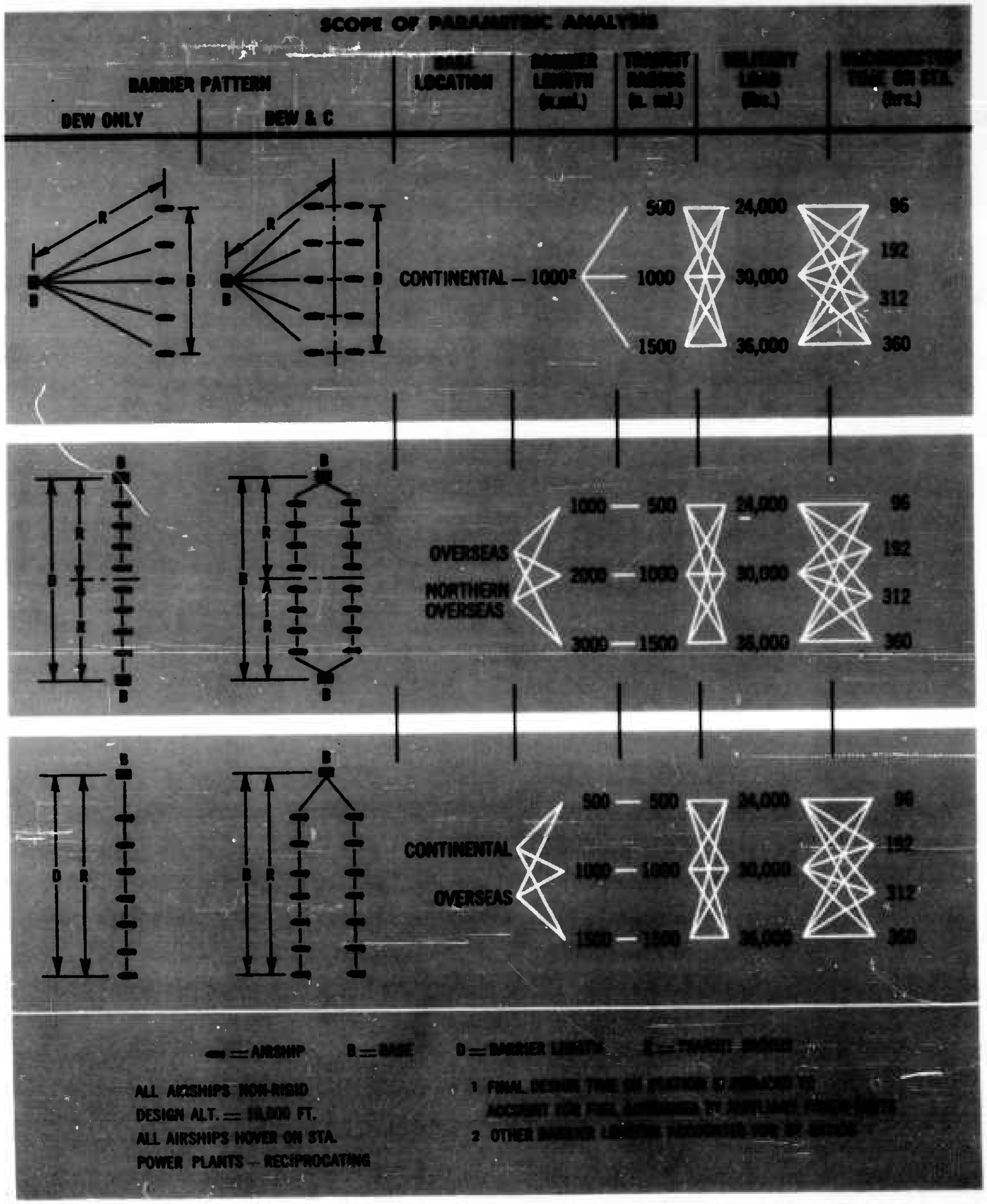

BARRIER PATTERN
DEW ONLY
DEW & C
LOCATION
CONTINENTAL — 1000²
500
1000
1500
24,000
30,000
36,000
96
192
312
360
OVERSEAS
NORTHERN OVERSEAS
1000 — 500
2000 — 1000
3000 — 1500
CONTINENTAL
OVERSEAS
500 — 500
1000 — 1000
= AIRSHIP
B =
D = BARRIER
ALL AIRSHIPS NON-RIGID
DESIGN ALT. = FT.
ALL AIRSHIPS HOVER ON STA.
POWER PLANTS — RECIPROCATING
1 FINAL
2 OTHER

FIGURE VII.1

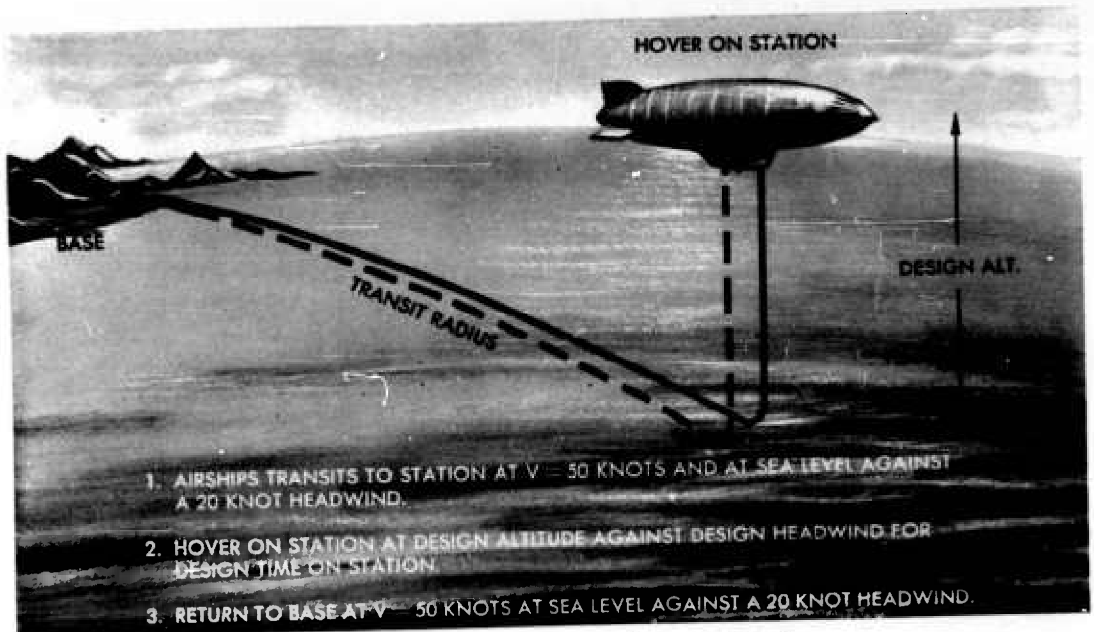


FIGURE VII.2 — TYPICAL MISSION PROFILE

Airship Characteristics

Speed

The on-station hover part of the mission requires only enough airspeed to counteract head winds. The transit portions of the mission require only sufficient speed to limit transit times to reasonable values. Consensus among operating personnel indicates that a modern airship should be capable of at least 60 knots cruising airspeed at design altitude. Airships designed to cruise at 55 per cent power with reciprocating engines will have a top speed of approximately 75 knots at normal rated power. All airships are designed to this speed requirement.

Altitude

Two opposing considerations are present in the selection of design altitude. The higher the altitude, the larger and more expensive the airship becomes. On the other hand, radar range increases with increased altitude, thus reducing the total number of airships required. Figure VII.3 shows the relationship of design altitude to total system cost. Minimum over-all costs

occur in the region of 10,000 feet. This altitude is chosen as the design requirement for all airships considered. It is readily apparent, however, that costs change very little between 9,000 and 12,000 feet.

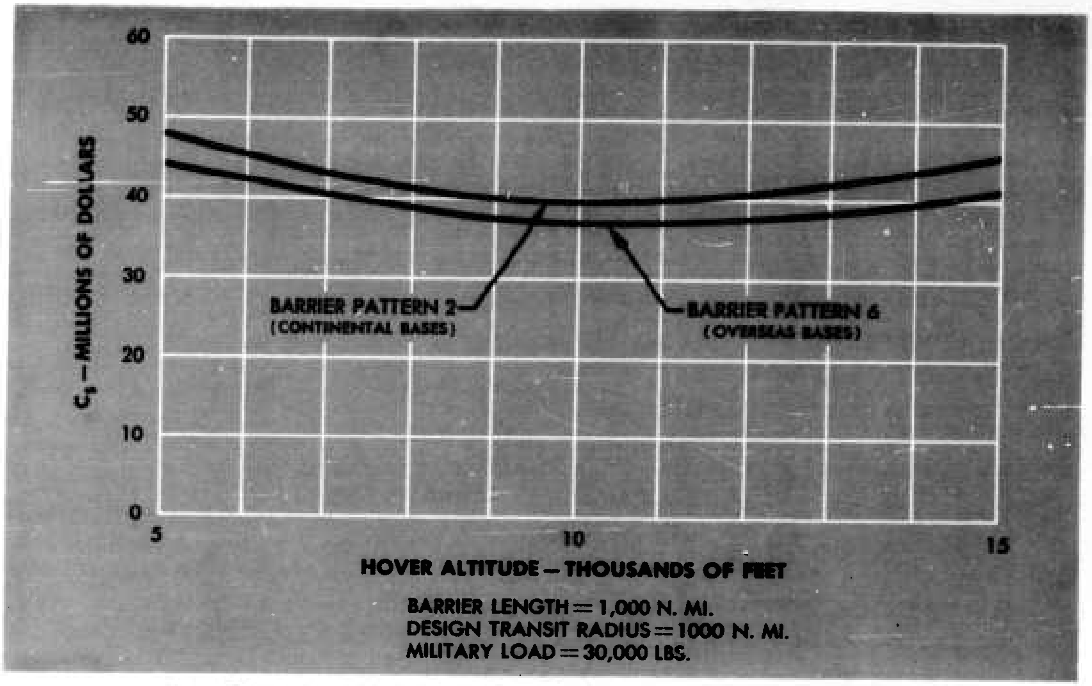


FIGURE VII.3 — COSTS OF AIRSHIP SYSTEMS VS. HOVER ALTITUDE

Head wind

All airships are designed with the capability of hovering on station at altitude with no head wind. That is, the airship is designed to reach equilibrium upon arrival at station. However, on station fuel requirements were determined in the Goodyear study (Reference 36), on the basis of the following average head winds:

Alt. (Ft.)	Head wind (Kts.)
0 - 3,000	20
5,000	25
10,000	30
15,000	40
20,000	60

Time On Station

The design time on station capabilities of the airships developed in Reference 36 were based solely on the fuel consumption rate of the airship power plants during hover on station. This analysis modifies those figures to account for the fuel used by the auxiliary power units required to generate the electrical energy for the electronic equipment. Fifty pounds of fuel per on-station hour are allowed for this purpose. (The equivalent of 75 Brake Horsepower, and an APU specific fuel consumption of .67 lbs./BHP/HR). This analysis considered six values of time on station: 49, 100, 135, 168, 198 and 224 hours. Representative curves of optimum times on station (exclusive of transit times) are shown in Figure VII.4. This figure shows that only minor variations in system cost occur between 135 and 200 hours. A value of 168 hours or 7 days on station, exclusive of transit time, has been selected as a suitable design time on station.

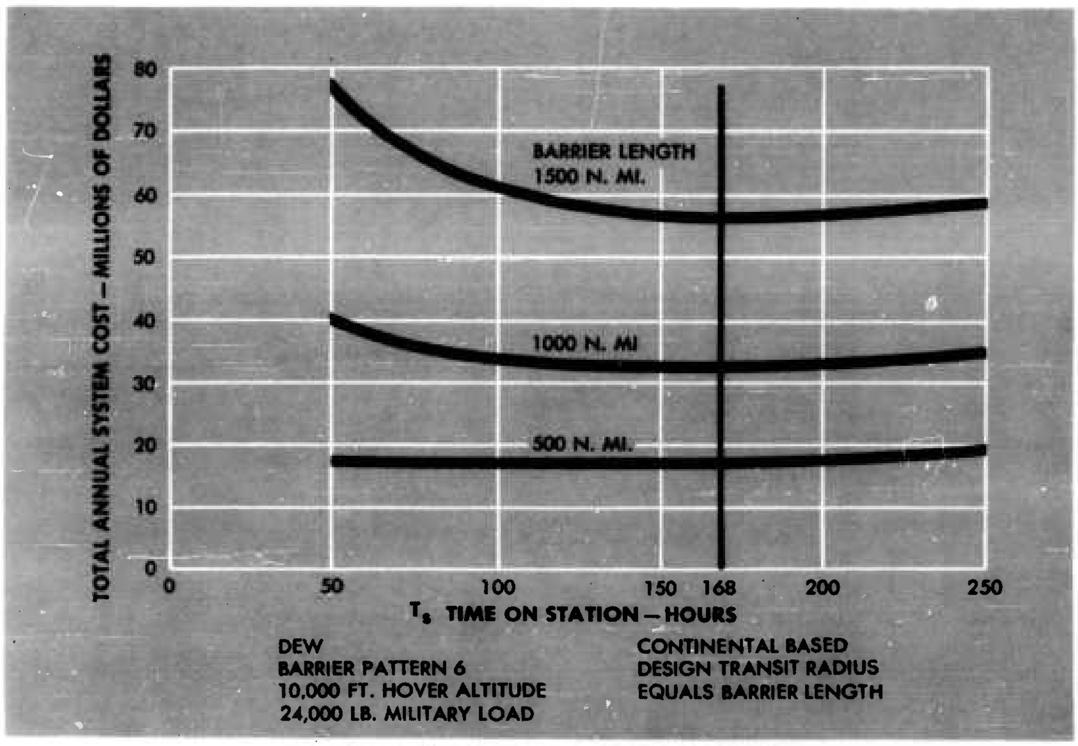


FIGURE VII.4 — OPTIMUM TIME ON STATION

Military Load

The airship military loads required are shown in Figure VII.5. They are basically similar to those described in Chapter V for the airplanes. In general, radome weights are reduced and personnel accommodations are increased for the longer missions. Providing a defense capability to the DEW system adds weapons and fire control gear, and crewmen to maintain a continuous watch during periods of tension. Providing the control function to the DEW & C systems requires the addition of a height finder radar and associated gear, additional control scopes and crewmen to operate the added equipment. Auxiliary power units are included in each military load to generate electrical power for electronic equipment. Parametric results are presented as a function of military load, in order to facilitate use of the data.

AIRSHIP MILITARY LOADS

	DEW	DEW + DEFENSE	DEW & C
COMMUNICATIONS & IDENTIFICATION	1,360	1,360	1,360
NAVIGATION	890	890	890
BASIC POWER SUPPLY, GALLEY, etc.	8,000	8,000	8,000
CREW & ACCOMMODATIONS	9,000	11,300	11,633
RADAR, SEARCH	3,185	3,185	3,185
AIRBORNE COMPUTER			
ECM		700	
HEIGHT FINDER RADAR, etc.		2,450	2,450
MISSILES AND COMPUTERS		3,150	
WATER CONDITIONER	300	300	300
SHOWER FACILITY	300	300	300
FOOD STORAGE 9.5 lbs./man/day less 1st day	2,310	2,910	2,990
TOTALS (approx.)	25,500 lbs.	34,500 lbs.	32,000 lbs.

FIGURE VII.5

Power Plant

The low speeds and long endurances required for the missions considered indicate the use of reciprocating engines. Reciprocating-compound engines offer somewhat better fuel consumption (Reference 36, page 73) but it is

doubtful if these engines will be available in the 1959-1964 time period in the small sizes required. A specific fuel consumption of .45 lbs./HP/HR is used, at cruise setting. Cruising horsepower is considered to be 55 per cent of normal rated power. Engine operating limits, fuel reserves, structural design criteria and general design requirements of current military specifications are observed. The actual numbers and locations of engines are not specified, but multiple engines mounted on outriggers appear desirable.

System Costs

Airship

To determine costs, the major components of airship car and envelope, power plant, and military load plus component spares, are examined separately. The cost of the car and envelope component is based on a rate per cubic foot of envelope volume. The power plant and military load items are costed by applying an average cost per pound.

Based on a life expectancy of 5 years, an annual replacement cost of the airship is determined. This cost is then increased by the operating expenses of fuel, crew and maintenance to obtain the total annual cost.

Costs for crew and military load, normally included in the total annual airship cost, are viewed separately to reflect variations in the DEW and DEW & C barrier patterns in respect to these items that occur independently of the airship configuration.

Crew

Airship crews vary in size depending on the requirements of the mission involved. The average monthly pay is determined for the number of officers and enlisted men required. Estimated training costs are then added before establishing annual crew costs.

Military Load

Military loads considered in this study include radar, communications, navigation, crew, miscellaneous, and in the case of DEW configuration, defense equipment as an option. However, since the crew is separately costed, the crew weight is deducted from the total military load and a weighted rate per pound is determined by assigning applicable rates to each of the various types of items comprising the balance of the military load.

Base

The cost of a base varies with the quantity and size of the airships based thereon. A representative base established in the ZI is assumed capable of servicing 25 ZP3K airships (527,000 cu. ft.). It includes two 5,000-foot runways, 20 mooring circles, tow-ways, large maintenance hangar, shops, administrative and recreational facilities.

Further assumptions have been made as follows:

1. The number of airships that can be serviced on a single base varies inversely with envelope volume of based airships.
2. Quantities in excess of 25 airships will result in a proportionate increase in base cost.
3. Cost of a base will not decrease below that for 10 airships.

The overseas base, due to logistic and operating cost factors, is estimated to cost 25 per cent more than the continental base.

Summary

Total system cost, C_S, represents the summation of the foregoing elements in terms of 1955 dollars expressed as follows:

$$C_S = N(C_{\text{Airship}} + C_{\text{Flight Personnel}} + C_{\text{Military Load}}) + k(C_{\text{Bases}})$$

where

N = System quantity of airships

k = Base location factor

Continental, k = 1

Overseas, k = 1.25

RESULTS OF THE ANALYSIS

This section deals with the effect on system cost of two radar performance levels and of various barrier tactical operations. Optimum DEW and DEW & C airship systems are determined for both single and double barriers and characteristics are tabulated. The selection of the optimum systems is accomplished by the application of the measure of effectiveness described in Chapter I. In general, all remarks assume the DEW system, but they are equally applicable to the DEW & C systems.

Effect on System Cost of Radar Parameter Changes

Performance Level

Analyses made in connection with the airplane and helicopter indicate that the effect on system cost of various levels of radar performance is relatively critical. The extent of penalties incurred, when the radar did not attain the originally designed performance level, was examined and the effect of this condition on system cost was determined. In the case of the airship, however, variations in radar performance result in minor effect on system cost. This results from two basic factors, first, . respect to system cost, an optimum altitude occurs at approximately 10,000 feet; and second, the airship configuration, as compared with the airplane and helicopter, allows considerable latitude in sizes and variations of radar antennas without materially affecting its performance and cost. In view of these indications, the airship parametric analysis is limited to an S-band or UHF radar system, flown at 10,000 feet altitude.

Radar Type and Antenna Size

For reasons explained above only one radar type is examined in the airship analysis. Furthermore, it is not considered necessary to compare various antenna sizes since such variations have little effect on system cost.

Radar Reflecting Area

As shown in the airplane and helicopter analyses, a reduction in radar reflecting area can dictate an increase in the force requirements to obtain the same level of detection, or it can require acceptance of a lower level of probability of detection with the spacing held constant. As an example, if spacing is decreased to obtain the 0.9 probability of detection against a 1 square meter target the increase in system cost is 14 per cent. If the spacing is held constant, the probability of detection against this smaller target is approximately 0.40. However, here again advantage can be taken of the ability of the airship to carry large antennas. The addition of an antenna of such size to obtain a high probability of detection on the missile target will increase the military load but the effect on system cost is slight.

General Factors Affecting System Cost

Base Configuration

Base cost remains an approximate constant of one-third of system cost regardless of transit radius, barrier length and time on station. This relationship exists because both base cost and system cost vary directly with system quantity, as shown in Figure VII. 6.

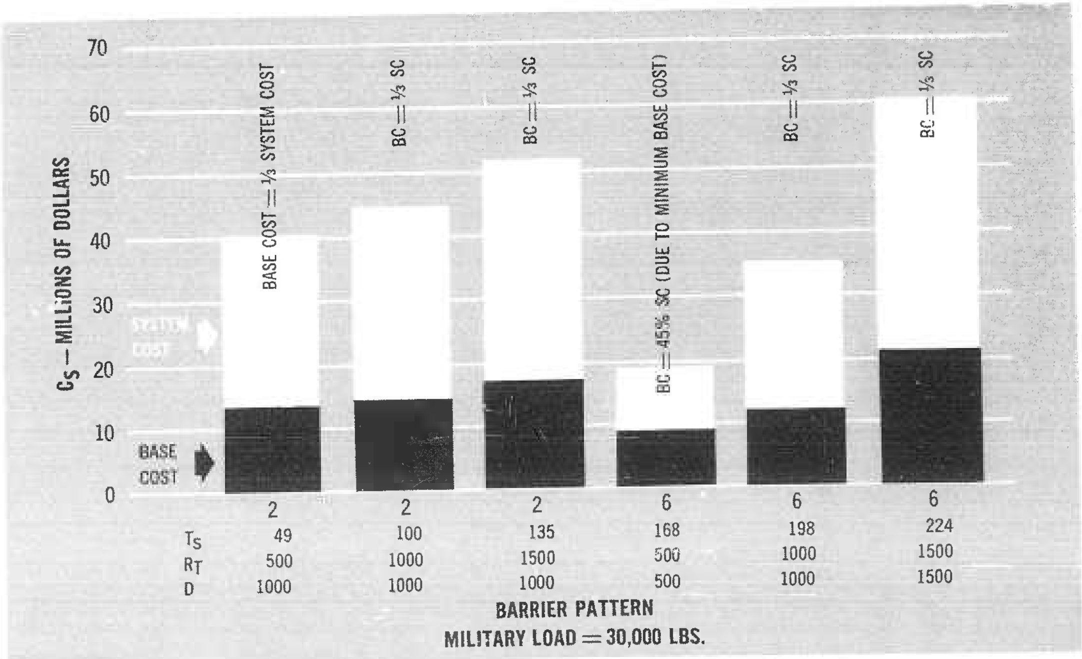


FIGURE VII.6 — RELATION OF BASE COST TO SYSTEM COST

Barrier Length

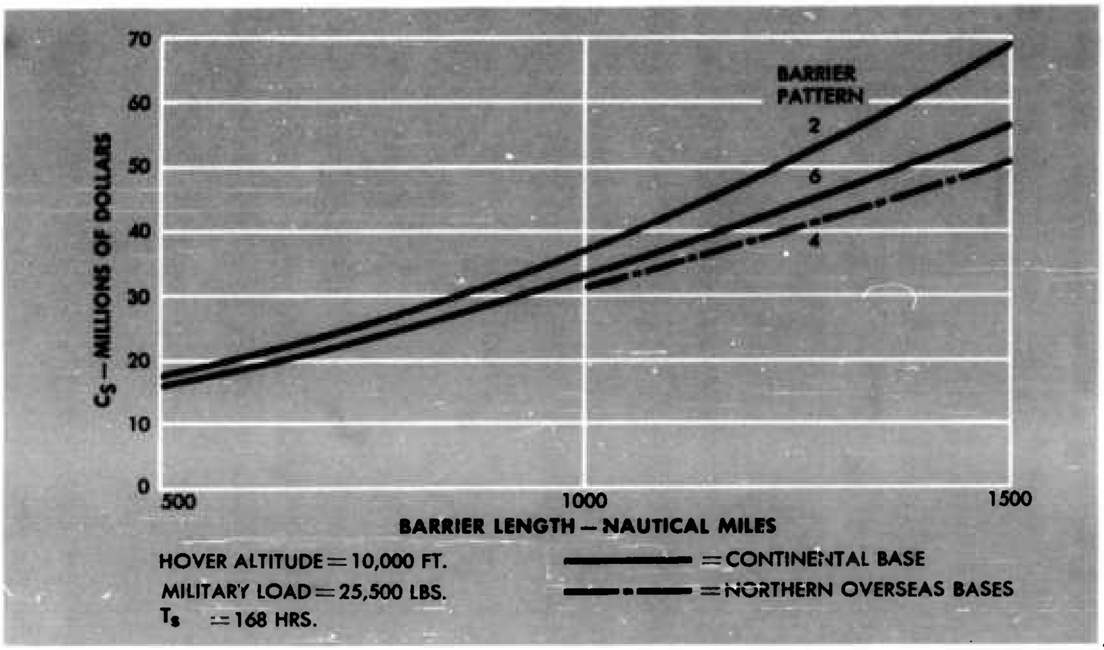
Barrier length affects system cost as shown in Figure VII. 7. With the longer barrier lengths, the additional stations and airships required will increase the cost of the systems.

Barrier Patterns

Six barrier patterns are analyzed in this study, three DEW and three DEW & C. Assuming a single barrier length of 1000 nautical miles, DEW barrier pattern 2 results in a higher system cost than DEW pattern 6 because transit distance to each station in the former is considered equivalent

to the longest transit distance in the latter. In pattern 6, succeeding transit distances are progressively shorter. The net effect of the longer transit distance in pattern 2 raises the system cost above that for pattern 6.

DEW barrier pattern 4 airships operate from two bases and fly half as far as airships following barrier pattern 6. The shorter transit distances in pattern 4 result in a lower system cost than that for pattern 6 when barrier length is longer than 1200 nautical miles, in spite of the cost for an additional base required under pattern 4. Comparative system cost of three DEW barrier patterns is shown in Figure VII. 7.



VII.7—COST OF OPTIMUM DEW SYSTEMS VS. BARRIER LENGTH

Endurance

Endurance capabilities in this study are represented by transit time plus time on station. For short endurances, geographic efficiency is low, that is, the fraction of total mission time spent on station is small compared to transit time. A significant fact is that the rate of fuel consumption in transit is approximately 3 times as great as when hovering on station. Ac-

cordingly, as endurance increases, system cost decreases until a point is reached at approximately 150 hours on station where further increases in endurance have relatively little effect on system cost. At this point transit time is proportionately smaller compared to time on station and the increased airship cost due to longer endurance requirements is offset by the smaller quantity of airships required. This relationship is shown in Figure VII. 8.

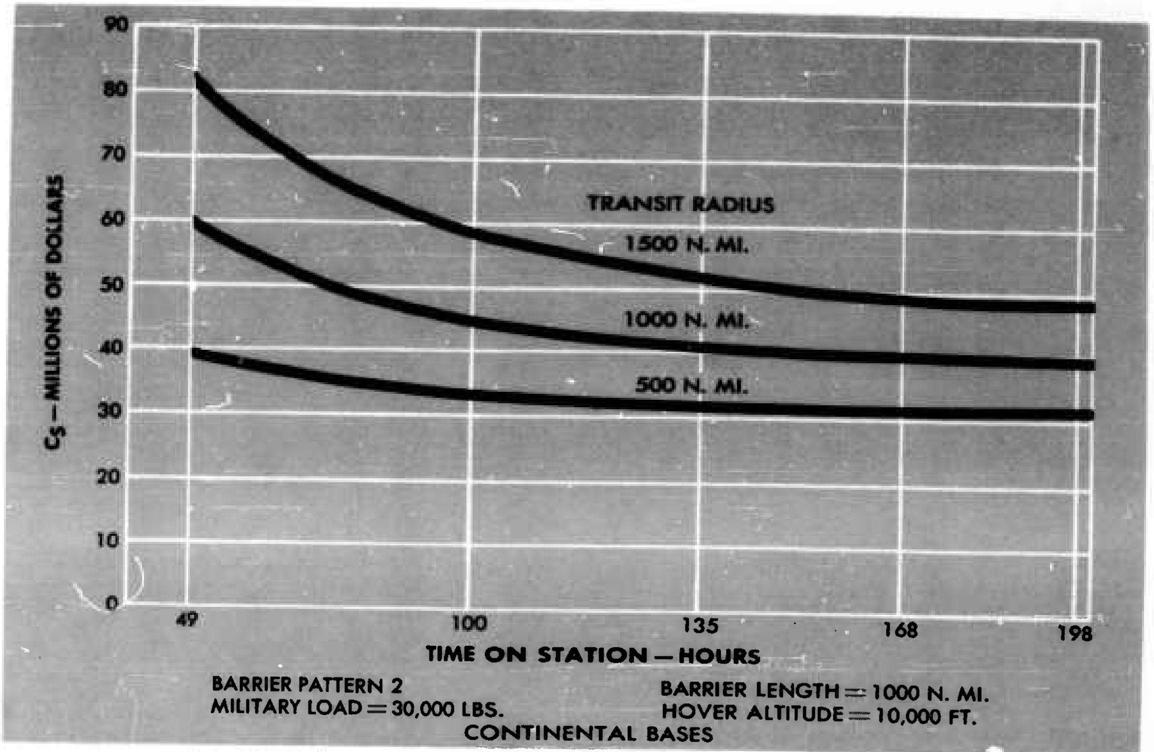


FIGURE VII.8 — COST OF DEW SYSTEM VS. TIME ON STATION

Altitude

The effect of altitude on system cost indicates that the lowest cost occurs at approximately 10,000 feet. At altitudes lower than 10,000 feet, the relatively large quantity of airships increases the system cost, and above 10,000 feet, the airship cost increases sufficiently to raise the system cost in spite of the smaller quantity of airships required. This effect has been shown previously in Figure VII. 3.

Navigation Limitations

The spacing between stations established in this study assumes reasonable navigation limitations by providing an overlap in radar coverage of approximately 5 per cent (refer Chapter II). If, for example, more severe limitations due to navigational difficulties are assumed, and decrease spacing from 281 to 200 nautical miles, the overlap in radar coverage increases from approximately 5 per cent to approximately 32 per cent with a resultant increase in system cost as shown in Figure VII.9.

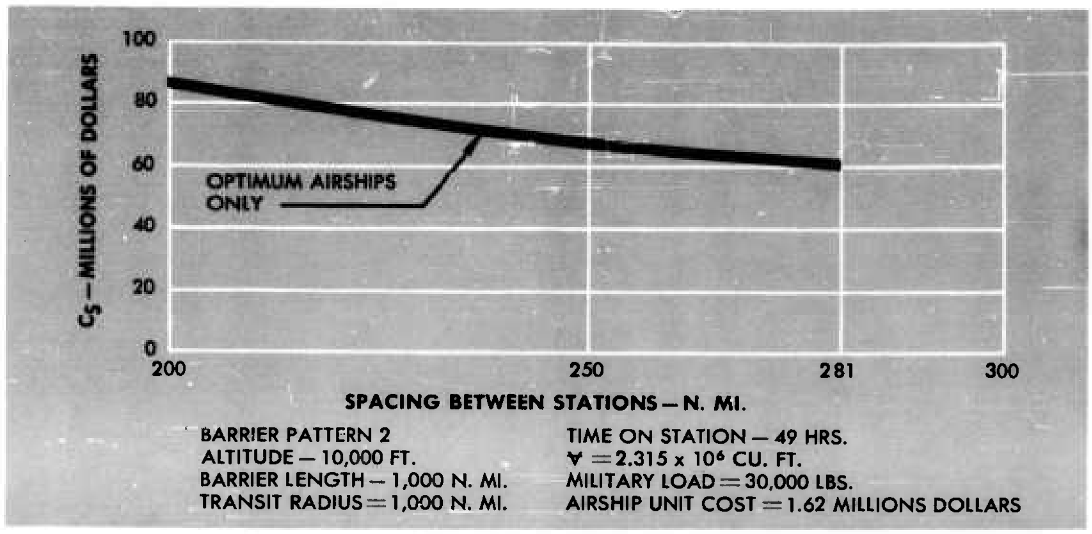


FIGURE VII.9 — EFFECT OF SPACING ON SYSTEM COST

Military Load

As the military load increases, its cost increases as well as the cost of the larger airship required to lift the added weight. These two factors increase the system cost an average of approximately 16 per cent when the military load increases from 24,000 pounds to 36,000 pounds. Figure VII. 10 illustrates this trend in the case of a representative airship.

Self Defense Equipment

Defense equipment added to DEW airships increases system cost in three ways:

1. Additional cost of defense equipment.

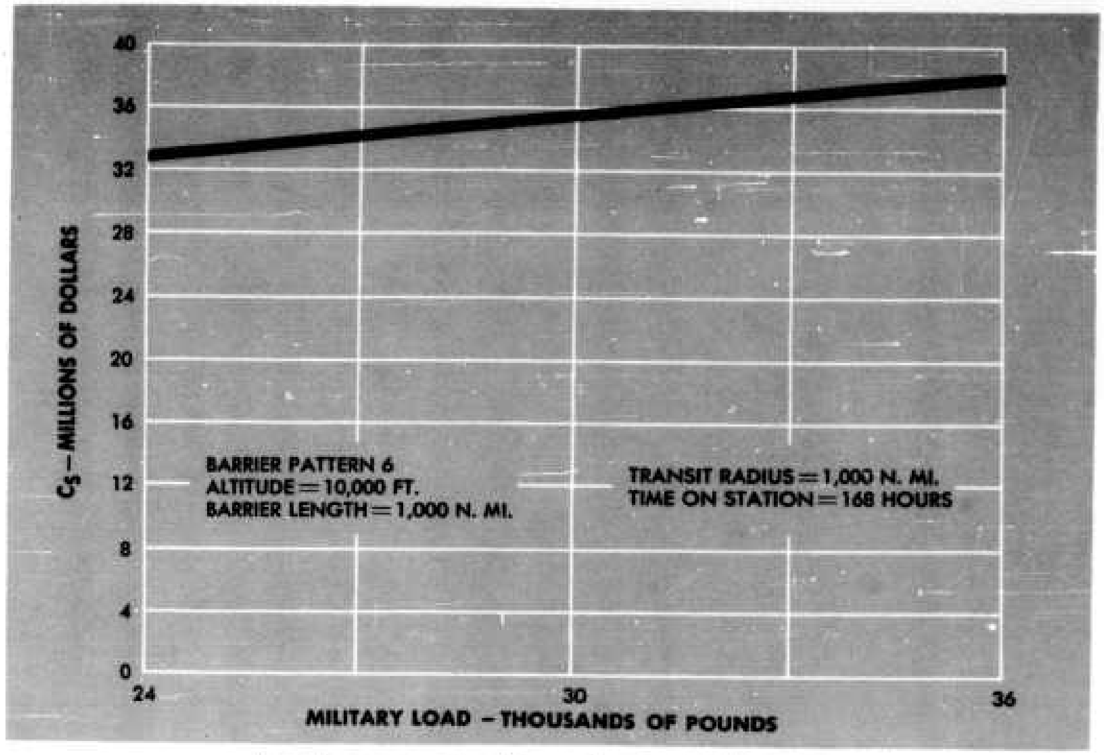


FIGURE VII.10 — MILITARY LOAD VS. SYSTEM COST

2. Cost of additional crew required to operate the defense equipment.
3. Increased cost of the larger airship required to lift the added equipment and crew.

Defense equipment increases the military load by 6,300 pounds. Figure VII. 11 compares the system cost of a DEW airship with a DEW airship plus added defense.

Head winds

The airship analysis is based on a constant design head wind of 30 knots during the entire time on station. This value of 30 knots is not the actual average wind to be expected, but is a design wind used to calculate fuel requirements. The 30-knot value is representative of the better weather regions of the world.

Designing for operation in more adverse weather areas where higher

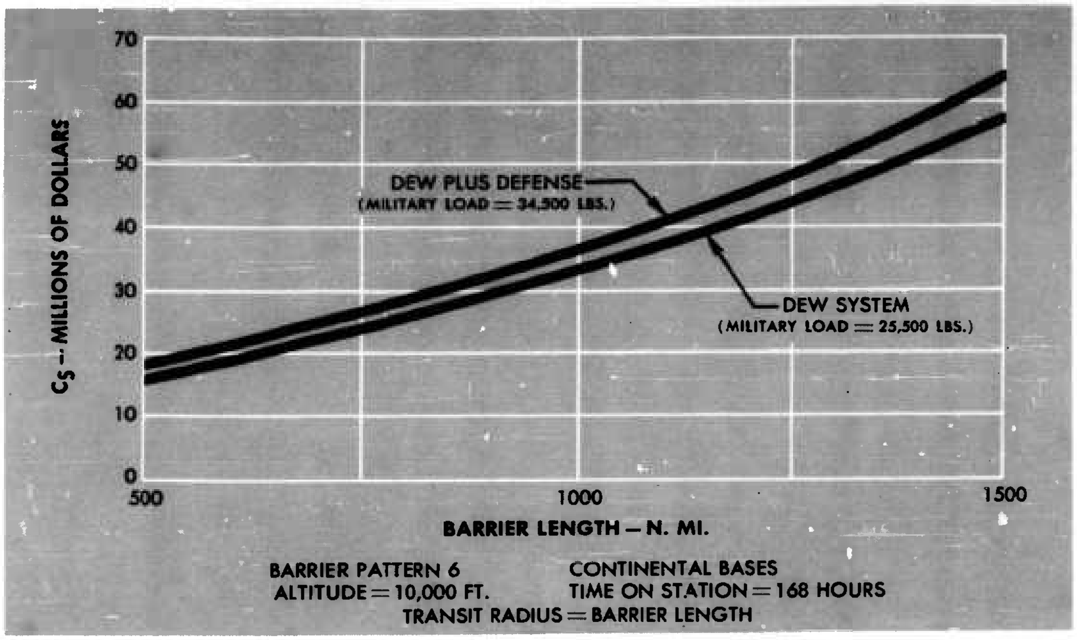


FIGURE VII.11 – EFFECT OF DEFENSE ON SYSTEM COST

average winds prevail will increase over-all system costs by approximately 10 per cent. For example, airships designed to operate in the Argentia area should be designed for an equivalent head wind of 40 knots based on average actual winds throughout the year. These figures and the discussion were directed towards DEW airship systems; but in the airship analysis DEW & C airship systems differ from DEW systems by essentially constant ratios, and therefore all comparative data pertaining to DEW airships applies to DEW & C airships.

Airship Utilization

All calculations of total system costs are based on an airship operational utilization of 240 operational hours per month. While in a squadron status, average flight hours per month are 344 hours. Figure VII.12 shows the variation of total system costs with airship operational utilization.

Characteristics of the Optimum Systems

DEW Airship Systems

The total numbers of airships required to maintain the various barriers

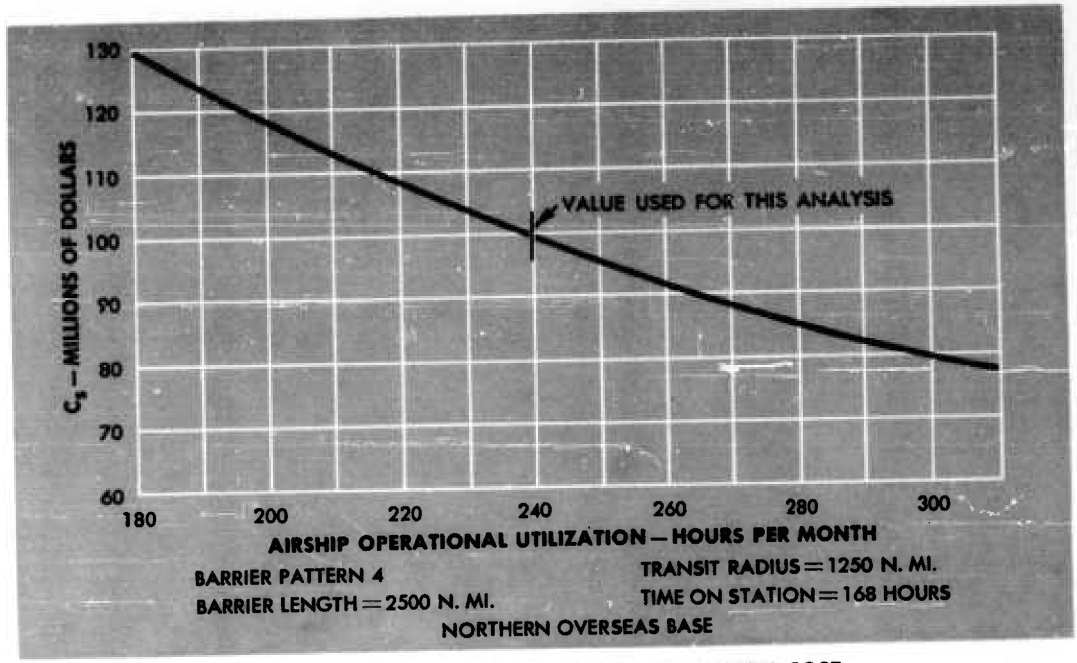


FIGURE VII.12 – AIRSHIP UTILIZATION VS. SYSTEM COST

are shown in Figure VII. 13. These numbers are obtained by using the equations shown in Chapter IV. Spacing between airships is determined by the radar capability and the level of detection desired. These considerations

QUANTITIES OF AIRSHIPS FOR DEW BARRIERS

BARRIER PATTERN	RADIUS, N. MI.	LENGTH, N. MI.	TOTAL SYSTEM QUANTITY, N, NO. OF AIRSHIPS TIME ON STATION, T_s – HOURS					
			49	100	135	168	198	224
2	500	1000	17.9	14.2	13.3	12.8	12.5	12.3
	1000	1000	25.2	17.8	16.0	14.9	14.3	13.9
	1500	1000	32.5	21.4	18.6	17.0	16.1	15.4
6	500	500	7.7	6.5	6.2	6.0	5.9	5.9
	1000	1000	18.4	14.5	13.5	12.9	12.6	12.4
	1500	1500	32.7	24.2	22.1	20.9	20.1	19.7
4	500	1000	15.4	13.0	12.4	12.1	11.8	11.7
	1000	2000	36.8	28.9	27.0	25.9	25.2	24.7
	1500	3000	65.3	48.4	44.1	41.7	40.3	39.3

FIGURE VII.13

are discussed in Chapter II. A spacing of 281 miles is used in computing the theoretical system quantities shown in Figure VII. 13. Fractional numbers of airships were carried through the analysis to furnish a more accurate feeling for trends.

Total annual operating costs of the optimum systems for the various conditions studied are shown in Figure VII. 14. These curves show barrier patterns 4 and 6 to be the most economical methods of operation. These curves also include a comparison of the costs of operating from continental versus offshore bases.

Figure VII. 15 shows the size and horsepower requirements of the airships for the optimum DEW systems. These airships carry 25,500 pounds of military load and are designed to hover on station 168 hours against a 30-knot headwind at 10,000 feet altitude.

Figure VII. 16 is a resume of the information contained in the preceding figures and shows the general characteristics of the optimum airship DEW systems.

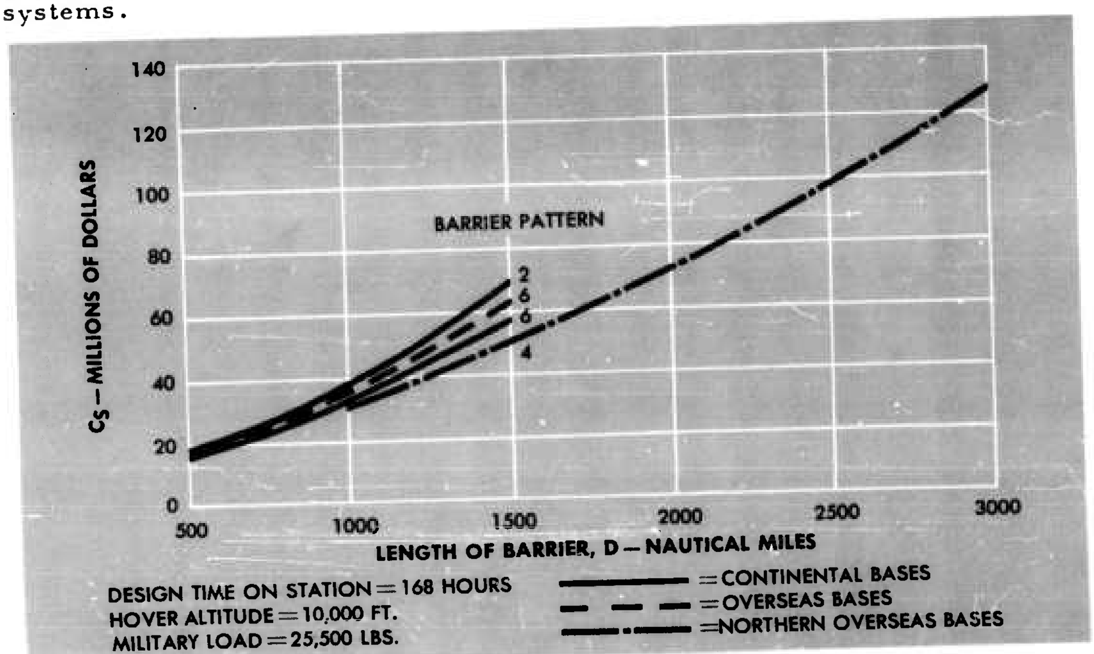


FIGURE VII.14 — COSTS OF OPTIMUM DEW SYSTEMS VS. BARRIER LENGTH

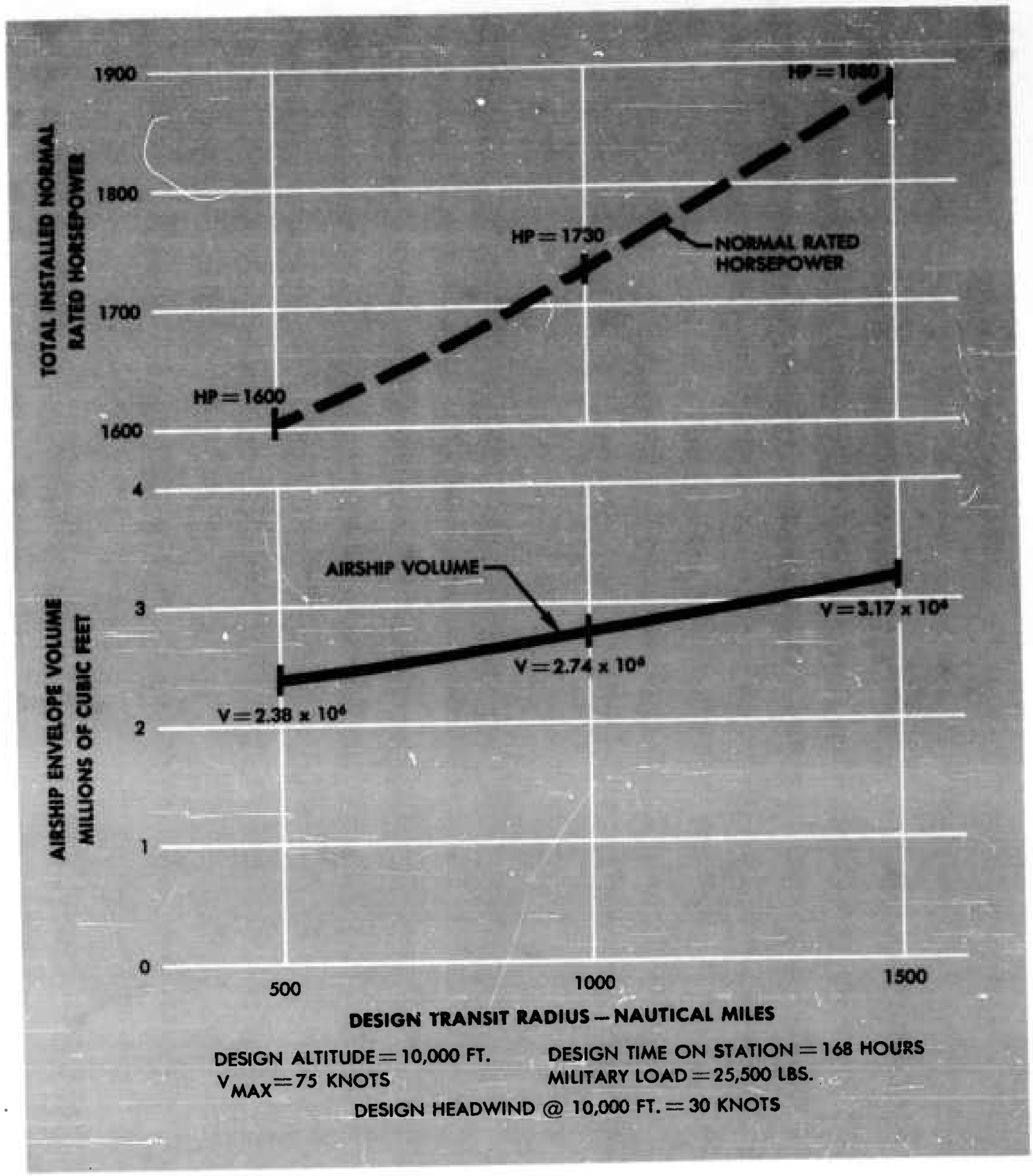


FIGURE VII.15 — DEW AIRSHIPS, SIZE & HORSEPOWER

SUMMARY OF DEW AIRSHIP SYSTEMS

BARRIER LENGTH, N. MI.	1,000	1,500	2,000	2,500	3,000
BARRIER PATTERN	4	4	4	4	4
AIRSHIP VOLUME, (millions of cubic feet)	2.38	2.55	2.74	2.94	3.17
ENDURANCE ON STATION, (hours)	168	168	168	168	168
ALTITUDE, (feet)	10,000	10,000	10,000	10,000	10,000
TRANSIT RADIUS, (n. mi.)	500	750	1,000	1,250	1,500
MILITARY LOAD, (lbs.)	25,500	25,500	25,500	25,500	25,500
INSTALLED HP	1,600	1,660	1,730	1,800	1,880
TOTAL SYSTEM QUANTITY, (number of airships)	12.1	18.7	25.9	33.5	41.7
ANNUAL COST PER AIRSHIP (millions of dollars)	1.57	1.63	1.69	1.75	1.84
TOTAL SYSTEM COST (millions of dollars)	31.0	50.6	72.6	98.0	127.5

FIGURE VII.16

QUANTITIES OF AIRSHIPS FOR DEW & C BARRIERS

BARRIER PATTERN	TRANSIT RADIUS N. MI.	BARRIER LENGTH, N. MI.	TOTAL SYSTEM QUANTITY, N, NO. OF AIRSHIPS TIME ON STATION, T_s — HOURS					
			49	100	135	168	198	224
1	500	1000	35.9	28.5	26.6	25.6	24.9	24.5
	1000	1000	50.4	35.6	31.9	29.8	28.5	27.7
	1500	1000	64.9	42.7	37.2	34.1	32.1	30.9
5	500	500	14.4	13.0	12.4	12.1	11.8	11.7
	1000	1000	37.8	28.9	27.0	25.9	25.2	24.7
	1500	1500	65.3	48.4	44.1	41.7	40.3	39.3
3	500	1000	31.0	26.0	24.8	24.1	23.7	23.4
	1000	2000	73.6	57.8	53.9	51.7	50.4	49.5
	1500	3000	130.6	96.7	88.2	83.5	80.6	78.6

FIGURE VII.17

DEW & C Airship Systems

Figure VII. 17 tabulates total theoretical system quantities of airships required for the different barriers and barrier patterns. Two lines of airships are used in the DEW & C barriers to provide sufficient tracking sur-

veillance. Spacing between airships is dictated by the height finder radar. Height finder antenna sizes were selected for the DEW & C airships to give spacings equivalent to those used in the DEW barriers.

Total system costs for the various barriers and barrier patterns are shown in Figure VII. 18. As in the DEW barriers, a pattern with a base on each end of the barrier is the most economical method of operation. Effects of base location, continental or overseas, are also shown.

Figure VII. 19 shows airship sizes and installed engine horsepower for the optimum DEW & C systems. These airships carry 32,000 pounds of military load and hover on station at 10,000 feet altitude for 168 hours against a 30-knot head wind. Figure VII.20 shows the general characteristics of the optimum DEW & C airship systems.

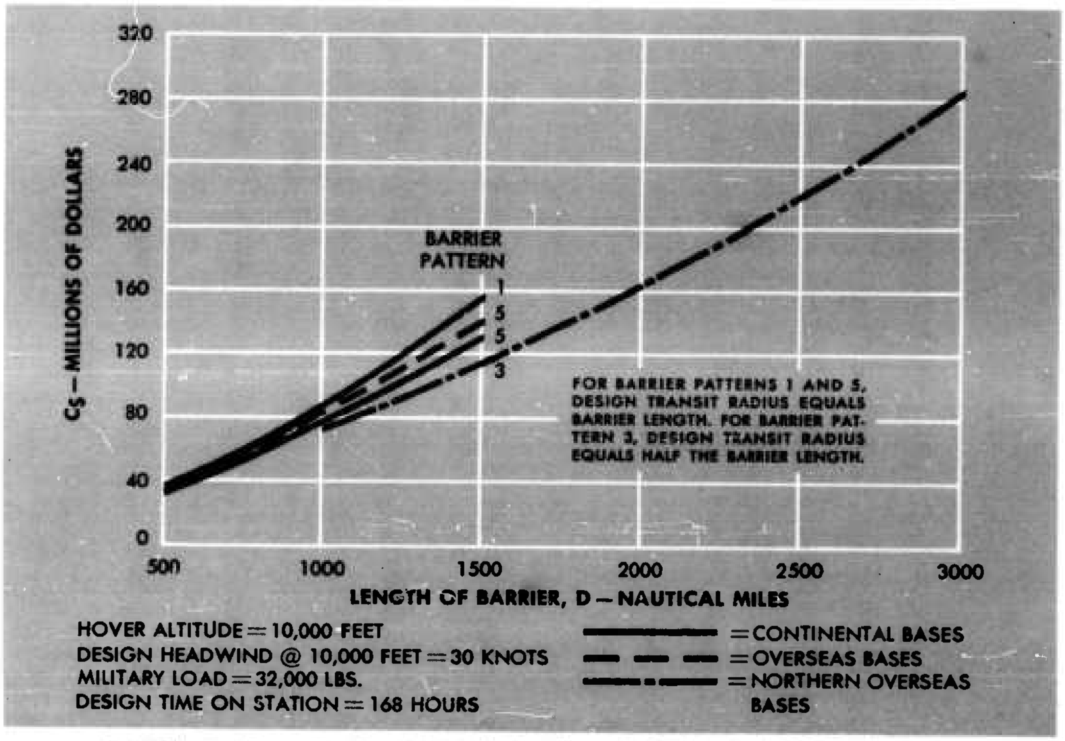


FIGURE VII.18 — COST OF OPTIMUM DEW & C SYSTEMS VS. BARRIER LENGTH

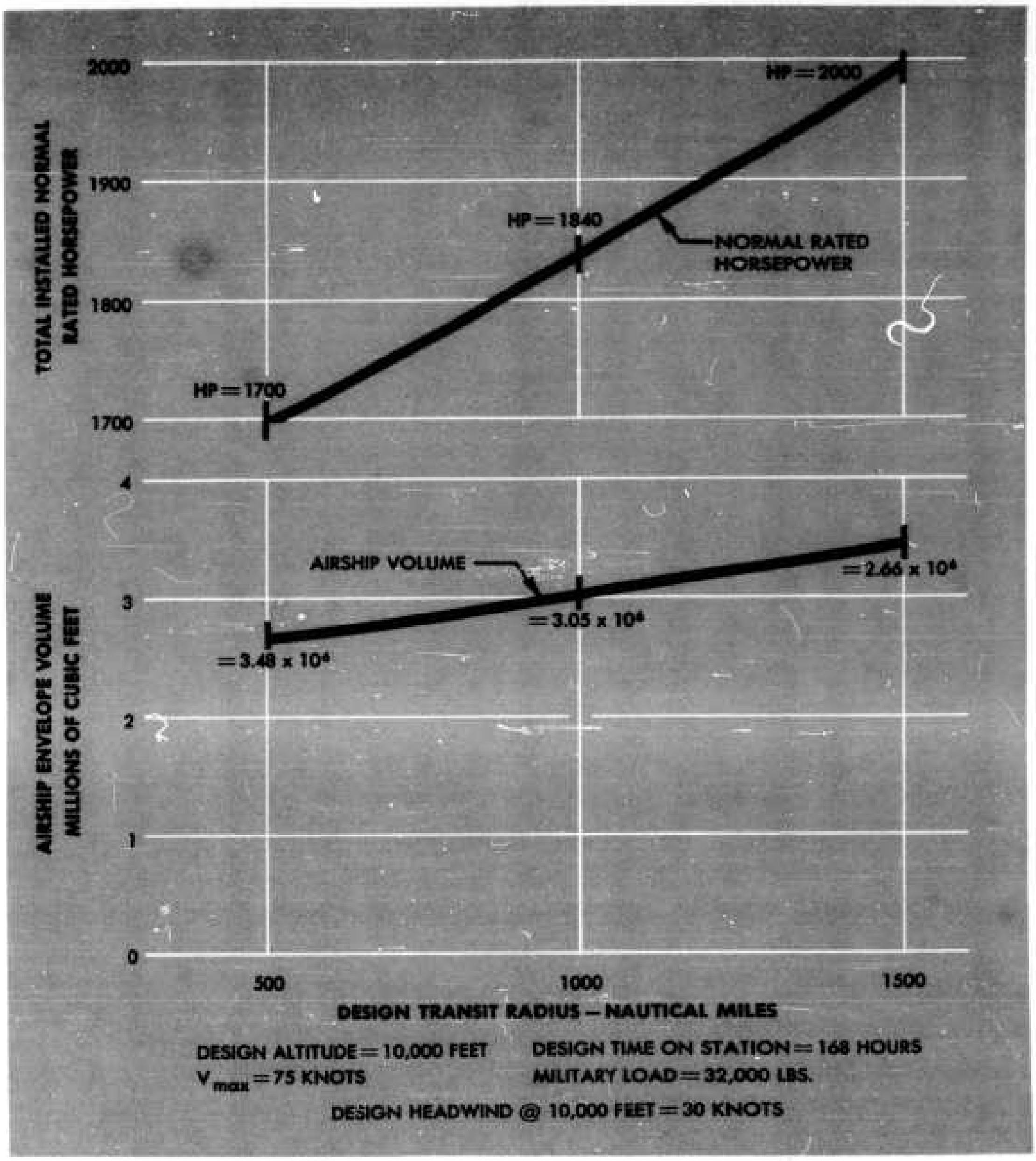


FIGURE VII.19 — DEW & C AIRSHIPS, SIZE & HORSEPOWER

Selection of Optimum Airship Systems

The selection of a different size airship for each barrier is, of course, impractical. To show the effect of designing a single airship capable of operating on more than one barrier, a calculation is made to illustrate the penalties that are incurred. A barrier network of 2500 and 1500 miles is assumed using barrier pattern 4. The airship designed for the 2500-mile barrier is examined when used in a 1500-mile barrier. For this barrier network the cost using the optimum airship in each barrier is 148.5 million. If the airship designed for the 2500-mile barrier is used in the 1500-mile barrier the network cost is 152.6 million. The penalty paid is only three per cent.

The airship selected as optimum operates in barrier 4. Since the selected airship must have the capability of flying the longest barrier assumed, the optimum airship is that one for the 2500-mile barrier pattern 4. This airship then has the capability of operating in any of the shorter barriers without severe penalty.

SUMMARY OF DEW & C AIRSHIP SYSTEMS

BARRIER LENGTH, N. MI.	1,000	1,500	2,000	2,500	3,000
BARRIER PATTERN	3	3	3	3	3
AIRSHIP VOLUME, millions of cubic feet	2.66	2.85	3.05	3.25	3.48
ENDURANCE ON STATION, hours	168	168	168	168	168
ALTITUDE, feet	10,000	10,000	10,000	10,000	10,000
TRANSIT RADIUS, n. mi.	500	750	1,000	1,250	1,500
MILITARY LOAD, lbs.	32,000	32,000	32,000	32,000	32,000
INSTALLED HP	1,700	1,765	1,840	1,910	2,000
TOTAL SYSTEM QUANTITY, number of airships	24.1	37.4	51.7	67.1	83.5
ANNUAL COST PER AIRSHIP (millions of dollars)	1.74	1.81	1.87	1.94	2.01
TOTAL SYSTEM COST (millions of dollars)	69.9	113.4	162.6	218.8	283.5

FIGURE VII.20

The selection of a single airship for the DEW & C barrier network follows the same line of reasoning as given above. The penalties incurred in this selection are nearly identical to those in the DEW case. The characteristics of the optimum airship systems for DEW and DEW & C are shown in Figure VII.21.

CHARACTERISTICS OF THE OPTIMUM AIRSHIP SYSTEMS

MISSION	DEW	DEW & C
BARRIER PATTERN	4	3
VOLUME, (million of cu. ft.)	2.94	3.25
ENDURANCE, (hours)	168	168
ALTITUDE, (ft.)	10,000	10,000
DESIGN TRANSIT RADIUS, (n. mi.)	1,250	1,250
MILITARY LOAD, (lbs.)	25,500	32,000
INSTALLED HP	1,800	1,910
ANNUAL COST PER AIRSHIP, (millions of dollars)	1,760	1.938

FIGURE VII.21

COMPARISON OF OPTIMUM DEW AND DEW & C AIRSHIP SYSTEMS

In this section an examination is made of the penalty incurred if the optimum DEW & C airship is used in a DEW barrier. This section also deals with the change in costs to the U.S. to establish a control barrier as compared to an early warning barrier.

Use of the Optimum DEW & C Airship in the DEW Barrier

It is of interest to examine the effect of using airships designed for DEW & C to maintain a DEW barrier. In this case, the DEW & C airship will be over-designed if used only for a warning function. The military load is increased by approximately 6,500 pounds in order to achieve the control

capability. This increase in military load dictates a larger airship. If this airship is used in a DEW barrier certain penalties are incurred. The extent of these penalties is shown in Figure VII.22. It is seen that one must pay approximately a 12 per cent penalty in system cost if the DEW & C airship is used in the DEW barrier.

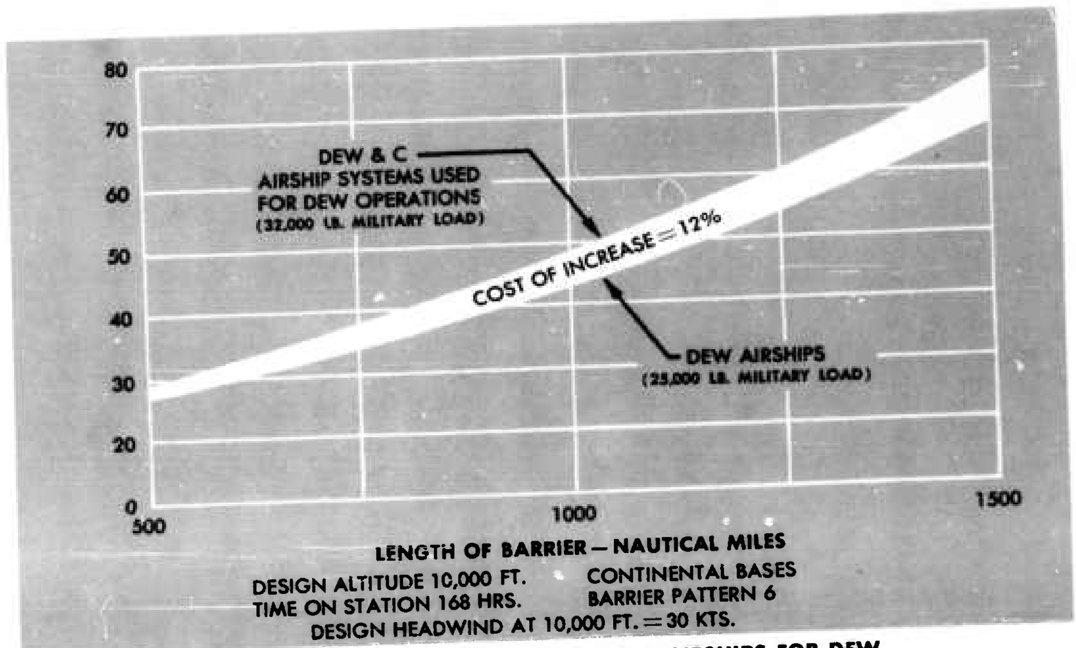


FIGURE VII.22 — COST OF USING DEW & C AIRSHIPS FOR DEW

Cost of Adding Control to an Airship Barrier

As has been shown, the effect of adding a control capability to a warning system is to increase the cost of this system. This increase in cost is caused by two major effects; (1) the increased size of the airship to carry the larger military load and (2) the larger number of airships to permit establishment of a barrier with the necessary depth.

Figure VII.23 is a bar chart summarizing the comparative costs for barriers utilizing early warning and early warning and control airships.

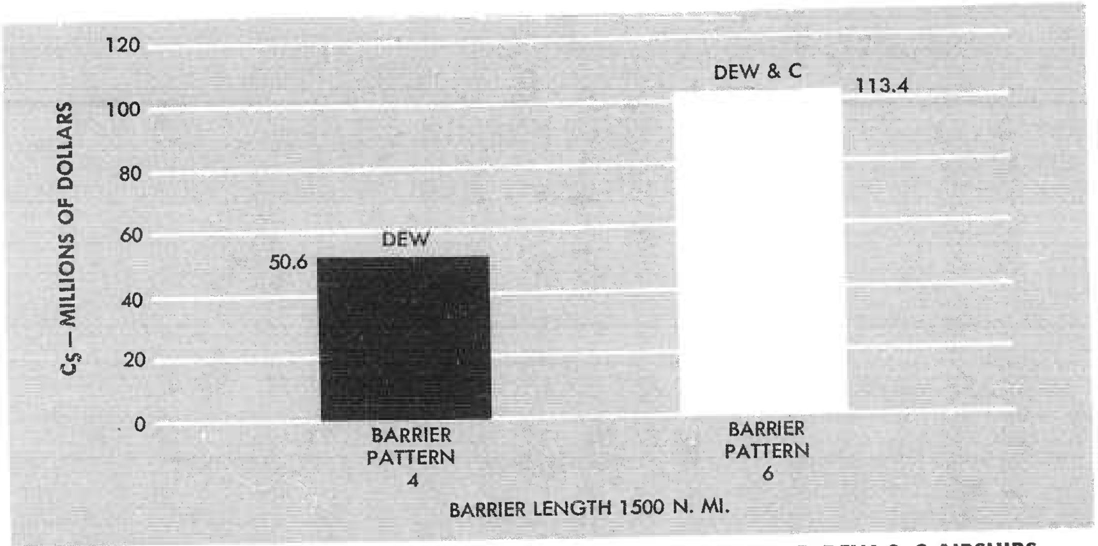


FIGURE VII.23 — SUMMARY OF COMPARATIVE COSTS FOR DEW AND DEW & C AIRSHIPS

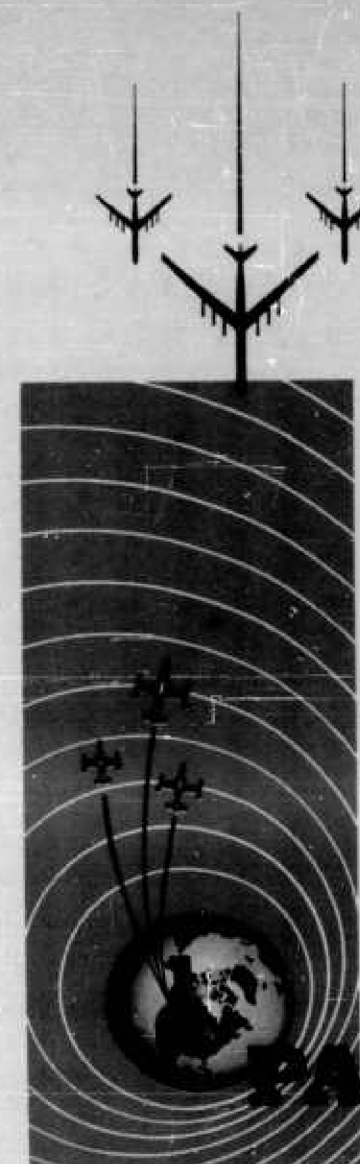
RECAPITULATION

The airship has the unique position of being capable of carrying with little penalty a large antenna and so is relatively independent of the level of radar performance. Internal mounting of the search antenna permits considerable latitude in weight and configuration. In spite of this ability to carry a large antenna, there is no advantage in designing for altitudes greater than 10,000 feet. Above this altitude the cost of the airship exceeds the gains of increased spacing.

The non-rigid airships are less expensive than rigid airships. Other design values of the optimum are: (1) Volume of 3.25 million cubic feet. (2) On station hover endurance of 168 hours, design transit radius of 1250 nautical miles. (3) Military load of 32,000 pounds. (4) Maximum speed of 75 knots.

The optimum configuration includes equipment for a control capability, since its inclusion causes only small penalties in over-all system cost.

Barriers with bases at each end are less expensive to operate than those with a base at one end, due to shorter transit radii and consequent smaller airships.



PART IV

- RESULTS AND CONCLUSIONS

INDEX TO PART IV

CHAPTER VIII

CHAPTER VIII
RESULTS AND CONCLUSIONS

This chapter summarizes the results and conclusions regarding the objectives of this study:

1. To determine the best airplane, helicopter and airship systems for both DEW and DEW & C; and from among these to select a single optimum system. Figure VIII. 1 lists the important characteristics of optimum aircraft.

2. To select aircraft for each of several possible barrier lengths.

3. Finally, to choose one aircraft for representative combinations of two barriers. The network considered includes barriers in the Pacific and Atlantic oceans. These are to be employed as sea wings of the continental defense system.

This procedure assures that the optimum system selected will remain efficient for any barrier system that the Navy may erect in the future.

Included are the affects of two divergent assessments of the possibility that moving target indication will be achieved. The analysis based on the positive premise, that MTI will be achieved, has been discussed in the preceding chapters. Results for the pessimistic assumption, that MTI will not be achieved, are drawn from Appendix A immediately following this chapter. Other important factors influencing the final selections are discussed and, finally, the recommended optimums are compared with contemporary airplanes.

OPTIMUM AIRPLANE SYSTEMS

Based on the premise that MTI is achieved, the characteristics of the optimum DEW and DEW & C airplane systems are given in Columns A and B of Figure VIII. 1. During the establishment of the sea wing barriers, the earliest requirement will be to provide information to the continental defense system. As this system expands, the additional requirement for a

CHARACTERISTICS OF OPTIMUM AIRCRAFT

	AIRPLANE			HELICOPTER		AIRSHIP		
	A	B	C	D	E	F	G	H
	DEW	DEW & C	DEW & C	DEW	DEW & C	DEW	DEW & C	DEW & C
	MTI	MTI	NON MTI	MTI	MTI	MTI	MTI	NON MTI
MILITARY LOAD (lbs.)	24,000	28,000	28,000	3890	7130	25,500	32,000	32,000
RADOME (ft.)	6.3x31.5	6.3x31.5	6.3x31.5	—	—	—	—	—
ANTENNA (ft.)	6x25	6x25	6x25	5x22.5	5x22.5	7.2x30	7.2x30	7.2x30
CREW	14	18	18	2	5	27	35	35
ALTITUDE (ft.) CRUISE OR HOVER	35,000	35,000	5000	20,000	20,000	10,000	10,000	5000
POWER PLANT	T-PROP	T-PROP	T-PROP	TURBINE	TURBINE	RECIP.	RECIP.	RECIP.
GROSS TAKE-OFF WT. (lbs.)	90,000	110,000	130,000	15,000	30,000	—	—	—
SPEED (kts.)	225	225	150	—	—	—	—	—
RANGE (n. mi.)	2940	3220	3440	—	—	—	—	—
ON STATION ENDURANCE HOURS				1.6	2.4	—	—	—
TIME TO CLIMB TO ALTITUDE HRS				0.3	0.3	—	—	—
TRANSIT RADIUS						1250	1250	1250
ON STATION ENDURANCE						168	168	168
VOLUME MILLIONS OF CUBIC FT.						2.94	3.25	2.40

FIGURE VIII.1

control capability may appear. These considerations should influence the selection of an optimum airplane system. In addition, Navy commitments in various tasks throughout the world dictate a control capability when early warning units are used in conjunction with fleet operations.

A comparison of the characteristics of the airplanes shown in Columns A and B of Figure VIII. 1 indicates that the addition of this control capability does not radically alter the airplane. As will be shown later, the penalty for using the DEW & C airplane in a DEW barrier is not severe. The choice

of a single airplane to carry out both missions simplifies problems of logistics support, training and procurement. Therefore, the analyses for the MTI and non-MTI cases were based on the inclusion of a control capability in the airplane.

As indicated in Appendix A the choice between the optimum airplanes for the MTI and non-MTI cases is clearly evident. If airplane design parameters must be selected for both high and low altitudes, the optimum airplane for the non-MTI case is the best choice. The characteristics of the optimum for this situation are shown in Column C of Figure VIII. 1. This low altitude optimum also has the advantage of having sufficient range to be more attractive for use in the Fleet Air Defense situation. Therefore, the optimum airplane selected is the one described above for the non-MTI DEW & C mission in Column C.

OPTIMUM HELICOPTER SYSTEMS

The characteristics of the optimum helicopter for the MTI case are shown in Columns D and E of Figure VIII. 1 for the DEW and DEW & C configurations.

The characteristics of the helicopters to carry out both functions differ widely, and severe penalties are incurred if the DEW & C helicopter is selected and is used in a DEW barrier. It is impractical to select a single helicopter to carry out both the DEW and the DEW & C missions.

Limiting the considerations of the helicopter to the DEW case, a single helicopter can be selected for the MTI and non-MTI case. The helicopter for the non-MTI case has inadequate installed horsepower to operate at the higher altitudes necessary for the MTI case. The optimum helicopter for the MTI case pays very small penalties at the lower altitudes. Therefore, the optimum DEW helicopter is the one for the MTI situation, Column D.

OPTIMUM AIRSHIP SYSTEMS

The basic design characteristics of DEW and DEW & C airship configurations for the MTI case are shown in Columns F and G, Figure VIII. 1. For the airship, as for the airplane, the addition of a control capability imposes small penalties when the control configuration is used in DEW.

Based on this consideration, only a DEW & C configuration is analyzed for the non-MTI case. The optimum for this situation is shown in Column H.

Three factors warrant the selection of the airship which can operate at 10,000 feet: (1) advantage can be taken of MTI, when it is achieved, (2) even if MTI is not achieved there are times in fair weather areas when operations at altitudes above 5000 feet are feasible, (3) considering refractive anomalies, it is desirable to operate as high above these as is consistent with sea state conditions and the optimum altitude as indicated by the measure of effectiveness.

Therefore, the optimum is the airship designed for operation at 10,000 feet altitude with the characteristics indicated in Column G.

SELECTION OF THE OPTIMUM SYSTEM

Optimum aircraft have been described for each of the three vehicle systems. The next step is concerned with the selection of optimum systems from among these three vehicles; where applicable, this choice is made for both the MTI and non-MTI cases. As a basis for such selection, the data are used for a representative combination of two barriers, 2500 and 1500 miles long.

Figure VIII.2 shows the comparative costs for aircraft configured for specific missions and designed for the MTI case. If a distant early warning system is to be selected, the helicopter system costs increase by about 15 per cent. If a control system is to be added, the situation is even more pronounced.

Figure VIII.3 illustrates the system costs when the early warning and control configuration is employed in an early warning network of barriers. Here again the DEW & C helicopter system is clearly not competitive, and is not considered for use in any mission.

The following discussion is concerned with comparisons of the optimum DEW & C airplanes and airships and DEW helicopters when employed in distant early warning operations. The airplane designed for the non-MTI case and the helicopter and airship designed for the MTI case have been selected as optimum. Figure VIII.4 shows the cost of systems using these aircraft in DEW barriers for both MTI and non-MTI cases. In the MTI case, if the radar performance level is achieved for which the airplane system is designed,

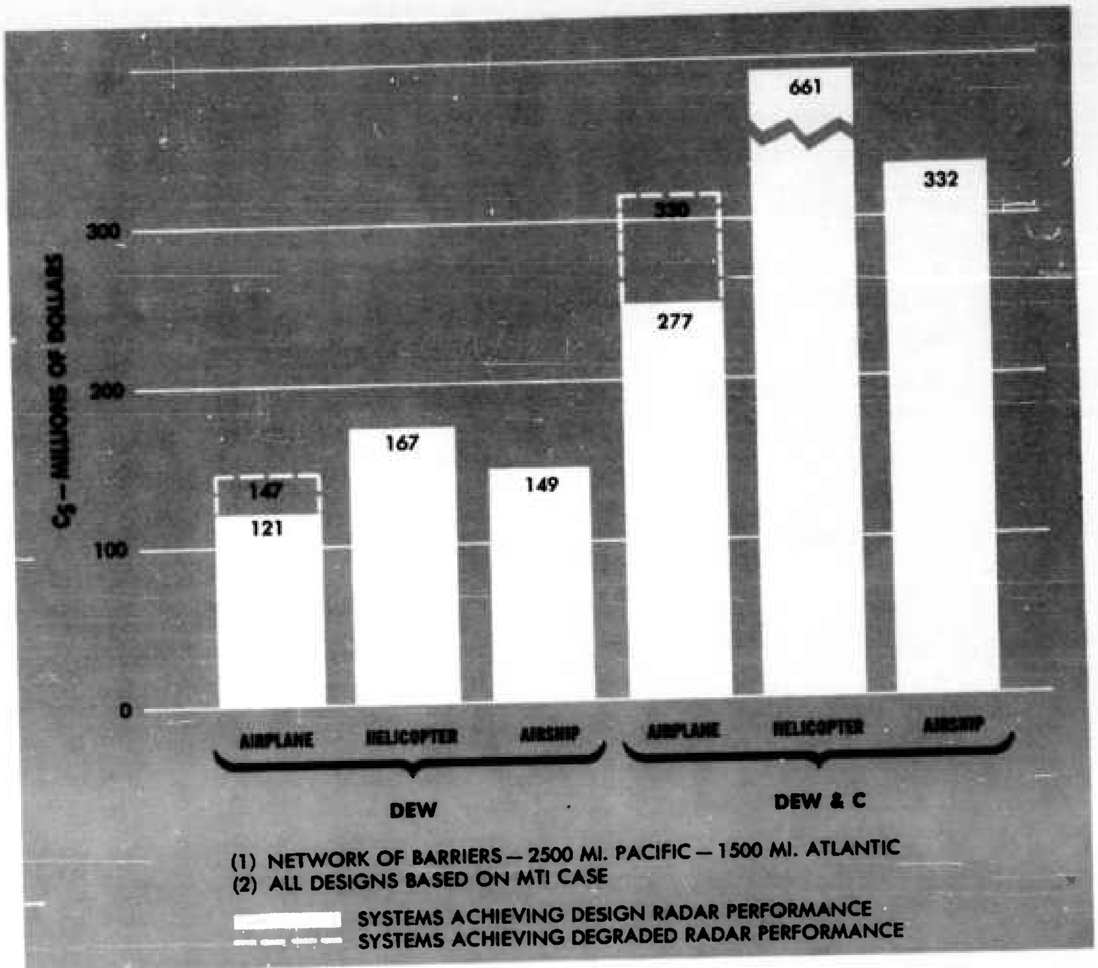


FIGURE VIII.2 — COMPARISON OF OPTIMUM AIRCRAFT SYSTEM COSTS

the airplane system is less costly than the airship system by about 20 per cent. The areas under the solid lines in Figure VIII.4 show the relative positions for this situation. If, however, the radar performance level for which the airplane system is designed is not achieved, the airplane and airship systems are competitive. The areas under the dotted lines in Figure VIII.4 show this situation. It is apparent that strong attention should be paid to obtaining good radar performance since a reduction in early warning system costs can be achieved.

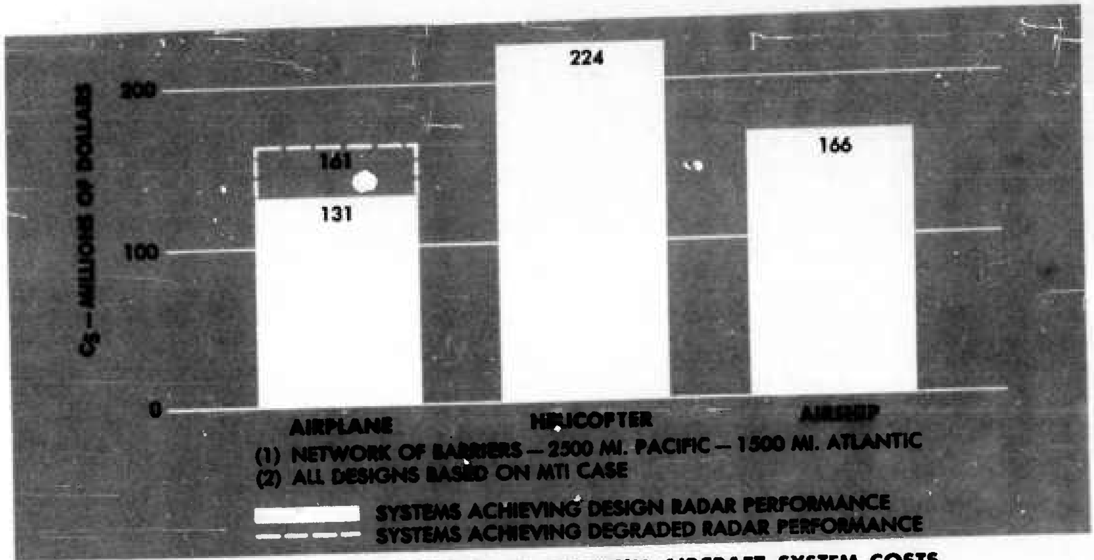


FIGURE VIII.3 — COMPARISON OF OPTIMUM AIRCRAFT SYSTEM COSTS DEW & C DESIGN IN DEW BARRIER

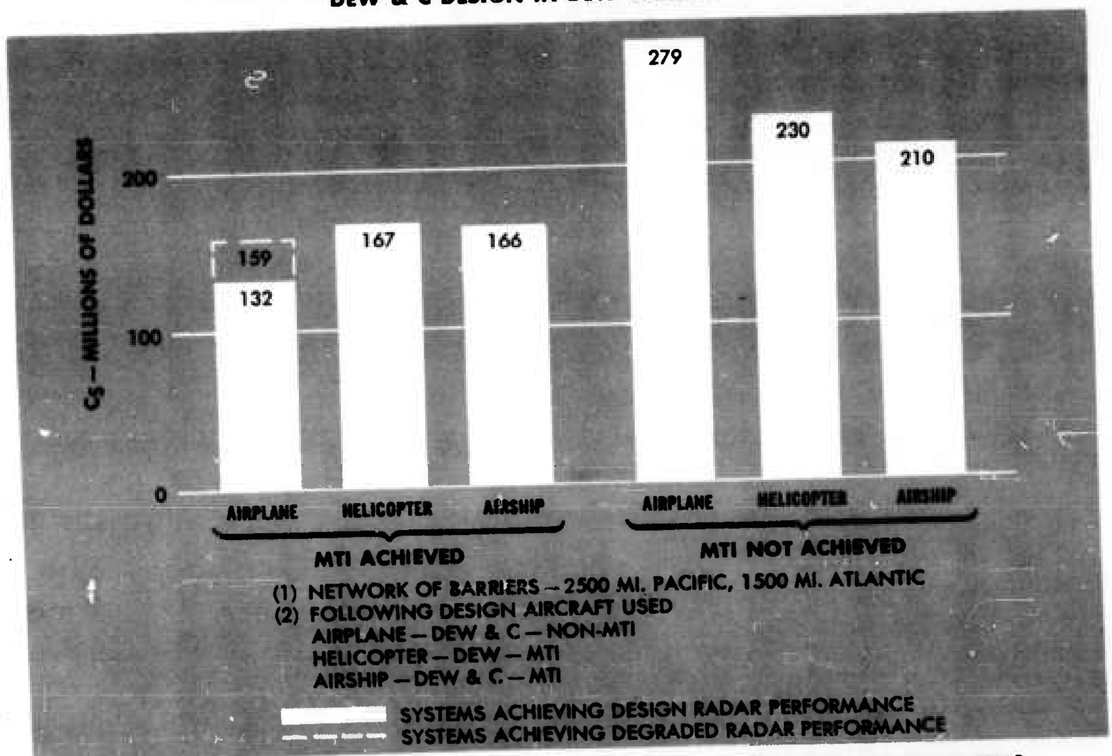


FIGURE VIII.4 — COMPARISON OF DEW SYSTEM COSTS USING SELECTED OPTIMUMS

The values for the DEW case shown in the various bar charts and in Appendix A are summarized in Figure VIII.5. This summary of the results clearly shows that the selection of an optimum system is directly dependent on the assessment of the probability of obtaining an adequate MTI system. The selection must be based on the following:

1. If MTI is not achieved, the airship system is optimum. It is approximately 35 per cent less expensive than the airplane system and

SUMMARY OF AIRCRAFT SYSTEM COSTS
DEW OPERATIONS

	ASSUMING MTI IS ACHIEVED								
DESIGN FOR	MTI			MTI			NON MTI		
FLOWN AT ALTITUDE FOR	MTI			MTI			MTI		
	CODE	DESIGN TYPE	SYSTEM COST	CODE	DESIGN TYPE	SYSTEM COST	CODE	DESIGN TYPE	SYSTEM COST
AIRPLANE	A	DEW	121[2] (147)[3]	B	DEW & C	131 (161)	C	DEW & C	132 (159)
HELICOPTER	D	DEW	167	E	DEW & C	224	—	DEW DEW & C	IMPOSSIBLE
AIRSHIP	F	DEW	149	G	DEW & C	166	H	DEW DEW & C	IMPOSSIBLE

	ASSUMING MTI IS NOT ACHIEVED					
DESIGN FOR	NON MTI			MTI		
FLOWN AT ALTITUDE FOR	NON MTI			NON MTI		
	CODE	DESIGN TYPE	SYSTEM COST	CODE	DESIGN TYPE	SYSTEM COST
AIRPLANE	C	DEW & C	279	B	DEW & C	290
HELICOPTER	—[4]	DEW	226	E	DEW	230
AIRSHIP	H	DEW & C	186	G	DEW & C	210

1. CODE FROM FIGURE VIII.1
2. SYSTEM COST—MILLIONS OF DOLLARS—BARRIER NETWORK
3. SYSTEM COST—MILLIONS OF DOLLARS—LOWER RADAR PERFORMANCE LEVEL
4. SEE APPENDIX A

FIGURE VIII.5

10 per cent less costly than the helicopter system. In addition, when compared with the helicopter system, it has a control capability which the helicopter does not have.

2. If MTI is achieved, and if the lower radar performance level is obtained, there is little difference in the costs of the three systems. However, the helicopter is designed for pure DEW and has no control capability. The airplane is slightly less costly than the airship and helicopter, but the difference is not of significant proportions.

3. If MTI is obtained, as well as a higher level of radar performance, the airplane system is the optimum. It is some 20 per cent less costly than the airship or helicopter.

SUPPLEMENTARY INVESTIGATIONS

In-Flight Refueling of Aircraft

Refueling for early warning airplanes is examined in Appendix B. The possible reasons which appear for developing a refueling capability are: to enable short-range airplanes to be used in the longer barriers; to extend the range of airplanes used in orbiting type barriers; and to permit the use of airplanes of lower gross weight to carry out assigned tasks.

These possibilities were examined and the following results were obtained:

1. When using the optimum airplane, (130,000 pound gross weight) refueling results in system cost savings of approximately 10 per cent.

2. If an airplane smaller than the optimum is used, (90,000 or 110,000 pounds gross weight) there is no saving in system cost.

3. There is no system cost advantage in using refueling to extend the range of aircraft in orbiting type barriers. In general, such use results in increased costs.

4. Refueling permits the use of the optimum airplane in the 2500-mile single-base barrier, but at greatly increased costs.

The general conclusion to be drawn from these results is that refueling

offers no significant advantage in any of the systems examined, but does add considerable complexity. A possible exception is that it permits flying barriers that cannot be flown under any other circumstances.

Combination Barriers

It has been suggested that barrier costs might be reduced by taking advantage of the radar coverage of ships that might be assigned to the barrier. Appendix C contains an analysis of the use of combination ship-airplane barriers.

The results of this analysis are:

1. The number of aircraft saved in the DEW barrier is less than the number of ships that must be added.

2. Combination airplane-ship barriers are more costly than pure airplane systems.

3. The employment of ships has no influence in reducing force requirements in the DEW & C barrier.

4. If aircraft are spaced to take advantage of the ship's low altitude coverage, the value of the ship as a communication relay or navigation check point is questionable.

5. If aircraft are spaced to enable them to communicate and navigate with the pickets the number of aircraft in the system will be at best, the same as those in a pure system.

In addition to all these considerations it must be realized that if a ship is assigned to, and is to be relied upon, in an early warning barrier, its usefulness in ASW is limited. On the other hand, if the picket has the authority to leave the line to follow up ASW contacts, its early warning value is lost. Then the airplane system must be capable of operating as a pure system.

The general conclusion that these results indicate is that there is little advantage in designing combination ship-airplane barriers for use against all-altitude targets.

IMPORTANT FACTORS INFLUENCING SYSTEM SELECTION

Certain factors emerge as the most important from the many that are examined in the course of this study. These, when varied, have significant effects on the selection of an optimum distant early warning system. This section discusses these important factors.

Development of MTI

It has been shown that the lack of an effective MTI has a far-reaching influence on the costs of any system and also on the selection of an optimum system. Airplane system costs are more than doubled if MTI is not achieved, and the airplane is forced to operate at lower altitudes. Airships and helicopters are somewhat less affected because their optimum altitudes for the MTI case are considerably lower. Therefore, the change in spacing between aircraft for the two conditions is less pronounced. However, costs are still materially affected; the helicopter costs increase approximately 40 per cent and airship costs more than 25 per cent. It is apparent that important benefits can be gained from a vigorous program for development of MTI.

Radar Performance Level

The optimum airplane systems have been selected on the basis of a radar system capability provided by a high standard of maintenance and equipment adjustment. It has been shown that this is the proper level for which to design, even if the expectancy of realizing it (rather than a degraded level) is only 15 per cent. The gain to be achieved in designing for the high level rather than the degraded level is 10 per cent, while the penalty for designing for the high level and getting the degraded level is about 1 per cent.

On the other hand, optimum helicopter systems have been selected on the assumption of a degraded radar performance level. In this case, the gain to be achieved in designing for the high level rather than the degraded level is less than 10 per cent, while the penalty for designing for the high level and getting the degraded level is nearly 30 per cent.

Figure VIII.6 summarizes these considerations and indicates the penalties and gains associated with the two courses of action.

The selection of an optimum airship is almost insensitive to radar per-

EFFECT OF RADAR PERFORMANCE LEVEL ON SYSTEM COST

DESIGN FOR	ACHIEVE		AIRPLANE			HELICOPTER	
1	1		42.9	PENALTY		57.5	PENALTY
1	2	GAIN	43.3	1%	GAIN	73.5	28%
2	2	10%	47.7		8%	62.5	
2	1		47.7			62.5	

FIGURE VIII.6

formance level. If, in anticipation of degraded radar performance, a larger antenna than that required by the airship optimum altitude of 10,000 feet is used, the airship size is not affected. Thus, if the higher radar performance level is achieved, only the airplane can take full advantage of such improvement. The airship and the helicopter systems will be improved to the extent of increased high altitude coverage, but the number of vehicles required and system cost will remain constant.

Utilization

The utilization value commonly used refers to the number of hours per month flown by aircraft assigned to a squadron while carrying out their mission. The values used in this study for utilization while aircraft are attached to the squadron are:

Airplane	200 hrs./mo.
Helicopter	75 hrs./mo.
Airship	344 hrs./mo.

These values, however, do not determine directly the back up factor for the aircraft in the system. This back up factor must be based on the average number of hours flown in barrier operations over the service life of the vehicle. Thus, the percentage of time that the aircraft spends in squadron status is of importance. Using numbers based upon statistical information of operations comparable to early warning, the average utilizations over the lives of the various aircraft were determined to be:

Airplane	150 hrs./mo.
Helicopter	45 hrs./mo.
Airship	240 hrs./mo.

These numbers indicate that the airplane and airship spend from two thirds to three fourths of their service lives in operational squadrons, and the helicopter about 60 per cent. The values given above are based on discussions with operational personnel. They represent extrapolations, taking into account a period of growth from 1955 to 1960. Of the three vehicles considered the least experience exists for the helicopter in operations resembling the early warning mission. Therefore, this value of 75 hours per month for squadron utilization may be somewhat optimistic.

The number of aircraft and system costs are directly affected by the values assumed for these utilizations. If the values differ from those given above, the relative positions of the airplane and airship may be altered particularly in the case where the lower level of radar performance is obtained.

Tactics

Tactics affect both aircraft selection and system costs. Tactics can change force requirements by a factor of two without altering the probability of detection. The optimum aircraft for a network of barriers must use the appropriate tactics for each of the barrier lengths comprising the network in order that system cost be minimized.

For airborne barriers greater than 1500 miles in length, the two-base system is always less costly than a single-base system. As barrier lengths approach those required in the Pacific, a single-base system imposes huge cost penalties. The military planner can easily afford to consider the establishment of bases at both ends of these longer barriers, or even a system of alternate bases in northern areas.

Control Capability

Incorporating a control capability with an early warning capability for airplanes and airships does not significantly alter the size of the aircraft or the over-all system costs. This, as previously discussed, is the basis for selection of a DEW & C airplane or airship, even though part of its life may be spent in pure early warning operations. For the helicopter, the addition of a control capability increases the costs to such an extent that no further consideration of this configuration is warranted.

CRITIQUE

During the course of the study, certain factors became apparent which might exert a considerable influence on the selection of the optimum systems. Such factors as could be assigned quantitative values were analyzed; but certain other factors remained which were difficult to evaluate quantitatively because adequate data were lacking, or because the framework of the study presented limitations. This discussion offers some qualitative remarks about these latter factors. These items become particularly important when two or more systems are competitive from the standpoint of the measure of effectiveness used in this study.

Vulnerability

The various aircraft types are vulnerable to enemy attack in varying degrees. While it is believed that the enemy can destroy the line if he wishes to expend the effort, the degree of effort required will be different against each of the three vehicles. The airship is the most vulnerable both because of its size, low speed, and lack of maneuverability. The helicopter presents a somewhat more difficult target because of its smaller size and its maneuverability but its lack of speed is a serious deficiency. The airplane is the least vulnerable of the three vehicles because of high speed, maneuverability, and altitude capabilities.

Mobility

Both the vulnerability of aircraft and the flexibility of the barrier are affected by the mobility of the three aircraft types, as discussed above. The effects of mobility on barrier operations are two-fold. First, the units have a flexibility within the barrier to replace the components of the barrier. Second, the barrier itself has mobility in the sense of the ability to modify old locations or establish new ones.

In the first instance, the helicopter system can replace aborted units in the shortest time and the airplane next, while the airship requires the longest time. For the second case, the mobility of the airplane is vastly superior and new barriers could be established in a few hours. The airship would require from four to five times as lon the airplane. The helicopter system

appears to be not even competitive, since the establishment of new barriers would be a matter of days, depending on the speed of the basing vessel.

Weather

Certain aspects of weather were examined quantitatively, but lack of adequate data restricted the analysis. The effects of surface weather conditions, extremes in weather (hurricanes, etc.), and icing, were examined only briefly. Here again, the three aircraft have varied abilities to cope with these bad weather conditions.

Surface weather conditions affect the ability to handle the aircraft on the ground or, in the case of the helicopter, on the deck of the sea base. For this situation the airplane is least affected. The helicopter rotor may be difficult to handle in high winds but the problems do not appear severe. The airship is the most difficult to handle under adverse surface conditions.

Icing is not a severe problem for any of the vehicles. The use of deicing and anti-icing techniques will permit any of the three aircraft types to operate in icing conditions.

Limited statistical information available on weather conditions at altitudes over the ocean indicates that barrier operations will be affected only a small percentage of the time by extremes of weather. The ability to cope with these extremes varies widely for the three vehicles. Neither the helicopter nor the airship has any capability to operate in extreme weather conditions. The airship can hold station in winds up to 75 knots but at the expense of time on station. Winds above this value will destroy the integrity of the line. The helicopters cannot operate in extremes of weather since both the sea base and the helicopter itself will be affected. In heavy seas, the operation from the sea base does not appear feasible. The airplane with its higher speed and its altitude capabilities has more ability to operate in these weather extremes.

ECM

Enemy employment of active ECM will degrade all the aircraft systems considered. This use of ECM will have no influence on the selection of optimum aircraft within a type, or on the selection of an optimum system. It does have a significant effect on the value of the early warning line, par-

ticularly a barrier that is established to control intercepts. The use of active ECM may be a type of warning in itself in the cold war situation.

COMPARISONS OF CONTEMPORARY AND OPTIMUM AIRPLANES

The optimum airplane system which has evolved from this study may be contrasted with the systems now being procured. For these comparisons the measure of effectiveness used is identical with that which led to the selection of the optimum airplane. The WV-2 airplane employing S-band and lacking MTI flies at approximately 2500 feet, an average altitude determined from an analysis of sea state distributions. Column I of Figure VIII. 7 gives data for this airplane. It has been suggested that the Lincoln Laboratory UHF kit

COMPARISON OF OPTIMUM AND CONTEMPORARY AIRPLANES

	I WV-2	II WV-2	III WV-2	IV OPTIMUM AIRPLANE
	S-BAND SEARCH RADAR—NO MTI	UHF SEARCH RADAR NO MTI	UHF SEARCH RADAR—MTI	UHF SEARCH RADAR MTI
MILITARY LOAD (lbs.)	30,000	30,000	30,000	28,000
RADOME (ft.)	4.8x20	4.8x20	4.8x20	6.3x31.5
ANTENNA (ft.)	4x17.4	4x17.4	4x17.4	6x25
NOMINAL CREW	27	27	27	18
ALTITUDE (ft.)	2500	5000	20,000[1] 15,000	35,000
SPEED (for maximum range, kts.)	190	200	225 210	250
RANGE (n. mi.)	3500	3500	2320 2620	3900
POWER PLANT	TURBO-COMP.	TURBO-COMP.	TURBO-COMP.	TURBO-PROP
GROSS TAKE-OFF WT. (lbs.)	145,000	145,000	145,000	130,000
TYPICAL SYSTEM COST (millions of dollars/year	407	326	270	132

1. HIGHER ALTITUDE IS USED FOR 2500 N. MI. BARRIER — LOWER FOR 1500 N. MI. BARRIER

FIGURE VIII.7

be fitted to these airplanes. Column II gives data for this configuration if the kit does not include MTI, Column III, if it does. The optimum airplane of this stucy is turboprop powered and flies at an altitude of 35,000 feet, an altitude which can be effectively used with UHF radar and MTI. Column IV shows characteristics for this sytem.

It is apparent from examination of the typical system costs that strong emphasis on the development of radar and compatible aircraft can produce significant economic benefits. The optimum selected from this analysis is approximately one third as costly as the present WV-2 equipped with an S-band radar and one half as costly as the WV-2 if it were equipped with UHF and MTI.

APPENDICES

A B C D

PART V

SUPPORTING DATA

- NON-MTI ANALYSIS
- REFUELING
- COMBINATION BARRIERS
- CONTROL REQUIREMENTS
- REFERENCES
- GLOSSARY

APPENDIX A

THE EFFECT OF NON-MTI RADAR ON SELECTION OF OPTIMUM AIRCRAFT

The importance of airborne search radar system performance in connection with the proposed concept of distant early warning and distant early warning and control barriers has been discussed in Chapter II. This appendix considers the effect on the selection of optimum aircraft and on system cost if the development of an effective MTI system is not achieved.

RADAR PERFORMANCE ANALYSIS

Past experience has shown that without MTI the flight altitude of an S-band radar system should be a function of the extent of sea clutter displayed on the radar scope (References 38, 39, 40). More recent operational evaluations of S-band radar by the Navy and Air Force confirm the need for relating the flight altitude to the sea state. In addition, in several instances, radar performance degradations were observed which provided good correlation with known refractive anomalies in the search areas.

The Lincoln Laboratory has conducted a series of experimental flight tests to compare the performance of 10 centimeter and 70 centimeter radar over the sea. (See Reference 7) These tests show the superiority of UHF radar, particularly under high sea state conditions. These results appear to indicate that without MTI, UHF radar systems can be flown at higher altitudes than the S-band systems for the same amount of scope clutter.

The importance of taking into account the distribution of sea state is shown by Figure A. 1, reproduced from Reference 7. This figure shows that during the winter months sea states 5 and above occur more than 50 per cent

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38. *Evaluation of the Capabilities and Limitations of Airborne Early Warning Equipment (Detection and Tracking of Aircraft).* COMOPDEVFOR, Seventh and Tenth Partial and Final Reports on Project OP/V26/F42-1, 31 March 1949. (CONFIDENTIAL)

39. *Determination of Capabilities of Carrier Based AEW Aircraft in Interception of Low Flying Targets.* COMOPDEVFOR, Seventh Partial Report on Project OP/V42/567-2 (REV.), 11 December 1952. (CONFIDENTIAL)

40. *Evaluation of the Limited CIC Installation of the ZP2M-3 Airship.* COMOPDEVFOR. Second Partial Report on Project OP/V149/F, 27 July 1954. (CONFIDENTIAL)

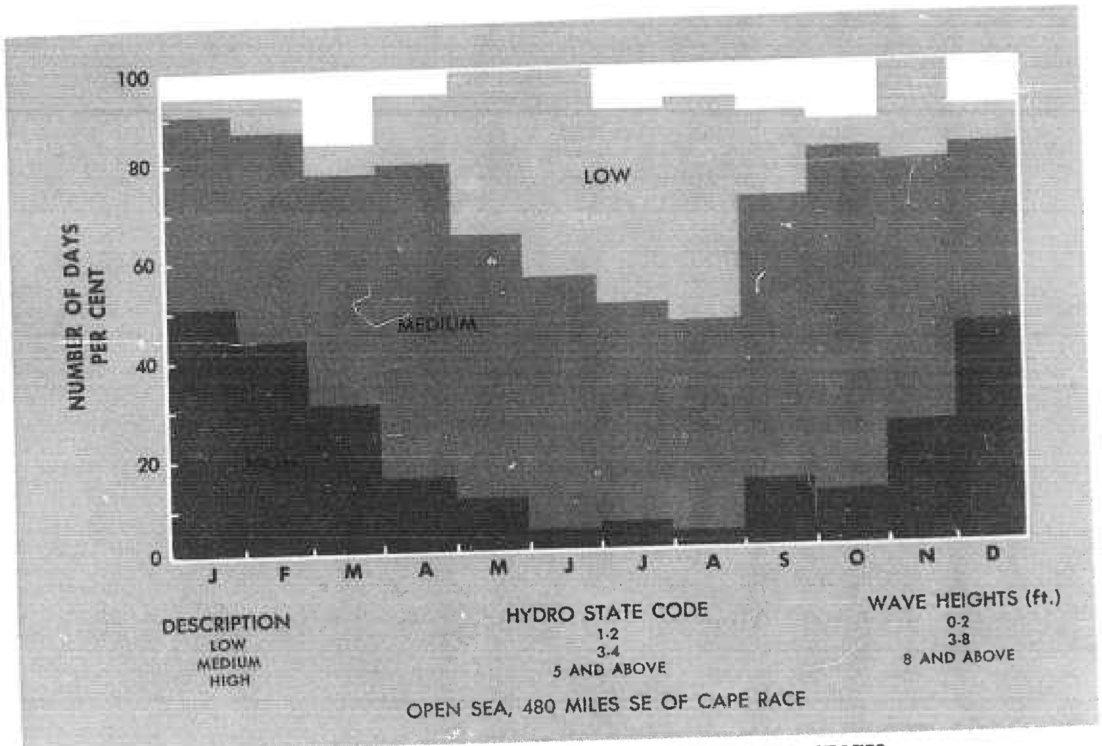

FIGURE A.1 – FREQUENCY OF OCCURRENCE OF SEA STATES

of the time. It should be noted that during the summer months when the sea states are lower and more favorable to radar search, the occurrence of refractive anomalies may be greater with attendant uncertainties of radar coverage. As will be discussed later, the effects of refractive anomalies on the spacing of barrier aircraft can only be qualitatively examined at this time because of the lack of sufficient statistical data.

Sea state is a function of wind velocity, duration, and extent of ocean over which the wind has been blowing. A plot of sea clutter radius as a function of surface wind and flight altitude with S-band radar is shown in Figure A.2. This plot, taken from References 38 and 41 shows that for a given surface wind the clutter radius varies approximately as the square

41. *Supplement to Lockheed Report 9740, Some Aspects of Airborne Early Warning and Continental Defense.* Memorandum Report No. 7084, Military Operations Research Division, Lockheed Aircraft Corporation, 25 April 1954. (SECRET)

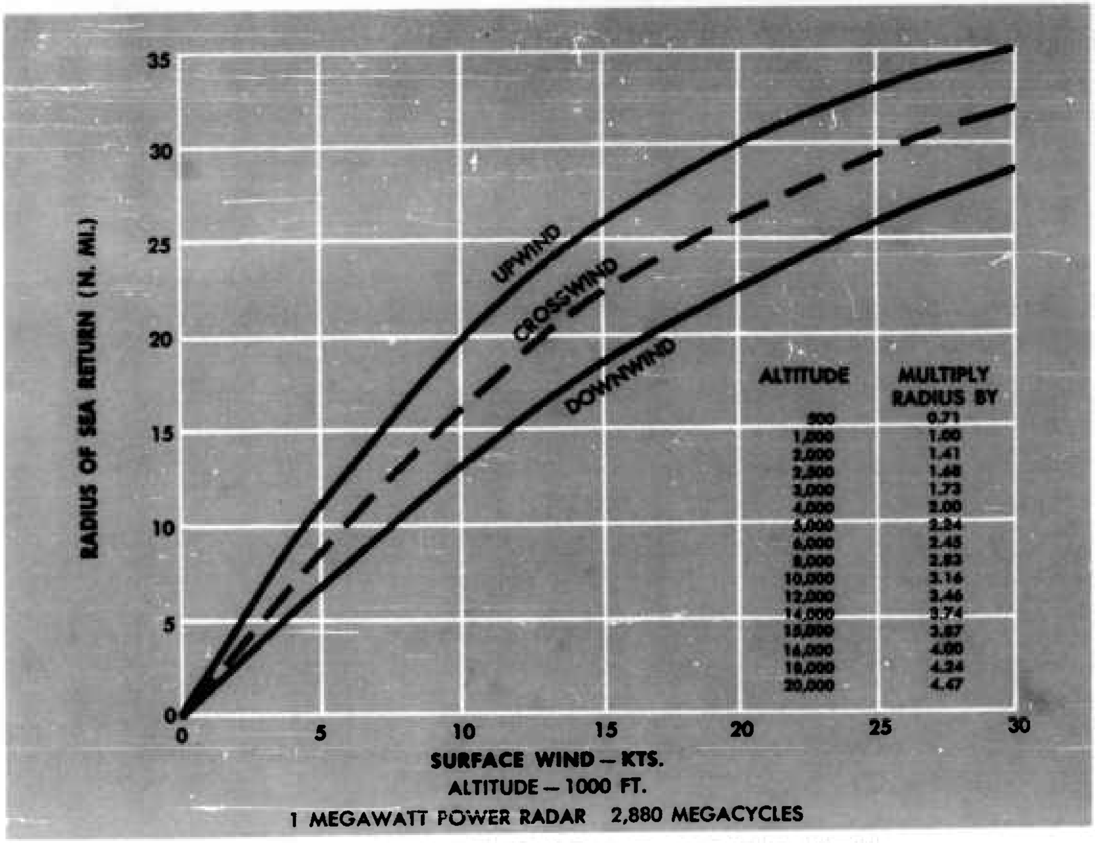

FIGURE A.2 — EFFECT OF SURFACE WIND ON RADAR RETURN

root of the flight altitude. These data are only first approximations, and do not take into account the change in sea clutter radius as a function of radar frequency, power and angle of incidence of the radar beam, the latter being a function of flight altitude.

The more important effects on radar and communication systems performance which result from flying the aircraft at the low altitudes determined by the sea clutter radius on the scope are the following:

1) The radar range for a selected probability of detection on low flying targets is limited by the horizon;
2) the frequency of occurrence and the intensity of refractive anomalies is greater at lower altitudes;

3) the control of weapons or interceptors is limited to areas within the clutter-free detection annulus where the target-to-clutter ratio is great enough to permit tracking; and
4) the line-of-sight communication range is limited by the horizon and the propagation path is more susceptible to the effects of refractive anomalies.

In addition to these items there are other factors, such as icing conditions, turbulent air, and cloud cover, which may at times adversely affect the performance of aircraft in barrier operations. (Reference 42) The major effect on barrier operations of flying the search radar system at the altitudes dictated by the sea clutter radius is to increase the force requirements for an equivalent level of detection in the barrier. That is, the inflight force requirements become in part a function of weather.

BLIP/SCAN RATIOS

In order to analyze the effect of low, medium and high sea states and associated flight altitudes on radar performance blip/scan curves were computed by extrapolation of experimental test data given in Reference 7. These curves are for S-band and UHF radars with characteristics similar to those listed in Figure II. 1 of Chapter II. The parameters that are varied are the flight altitude and the sea state. These blip/scan curves are shown in Figure A. 3 and indicate the effect of varying these parameters. The radar reflecting area of the target is 7 square meters and radar performance level 2 as defined in Chapter 2 is assumed.

By taking sea state distributions and blip/scan ratios into account an average flight altitude of 2500 feet for S-band and 5,000 feet for UHF radar systems is indicated. With high sea states the control and height finding capabilities of both S-band and UHF systems without MTI are so marginal that further consideration of this mission function does not appear to be justified.

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42. J. A. Smithson, *Factors Affecting the Operations of AEW & C Airplanes*. Report LR 7095, Military Operations Research Division, Lockheed Aircraft Corporation, 1 February 1955. (CONFIDENTIAL)

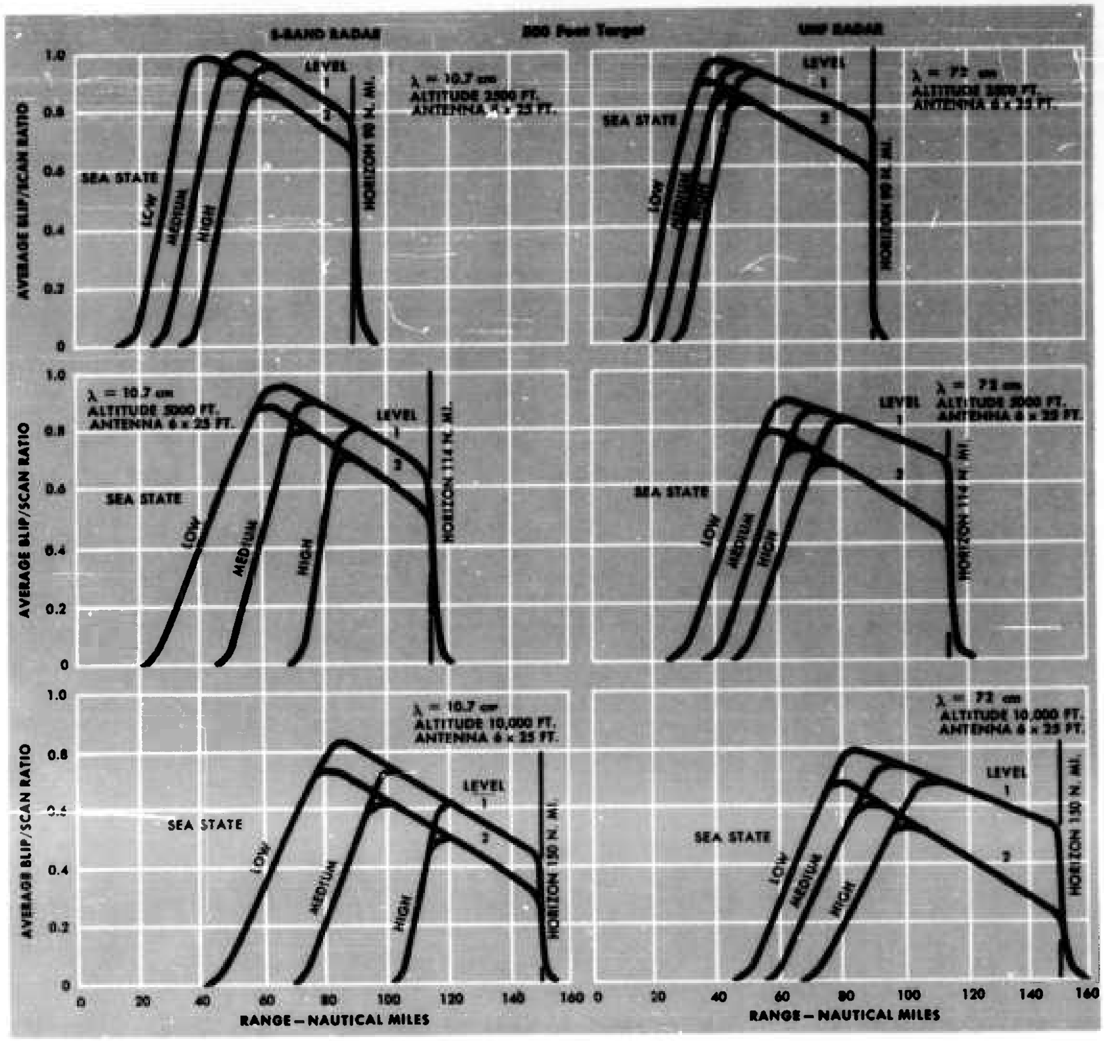

FIGURE A.3 — BLIP/SCAN RATIOS

LATERAL RANGE CURVES

For purposes of determining the spacing of barrier aircraft, lateral range curves shown in Figure A.4 were computed from the blip/scan data shown in Figure A.3. These curves show the probabilities of detection versus lateral range X. On the basis of best available test data, the double blip hypothesis is assumed for the S-band radar and the single-blip for the

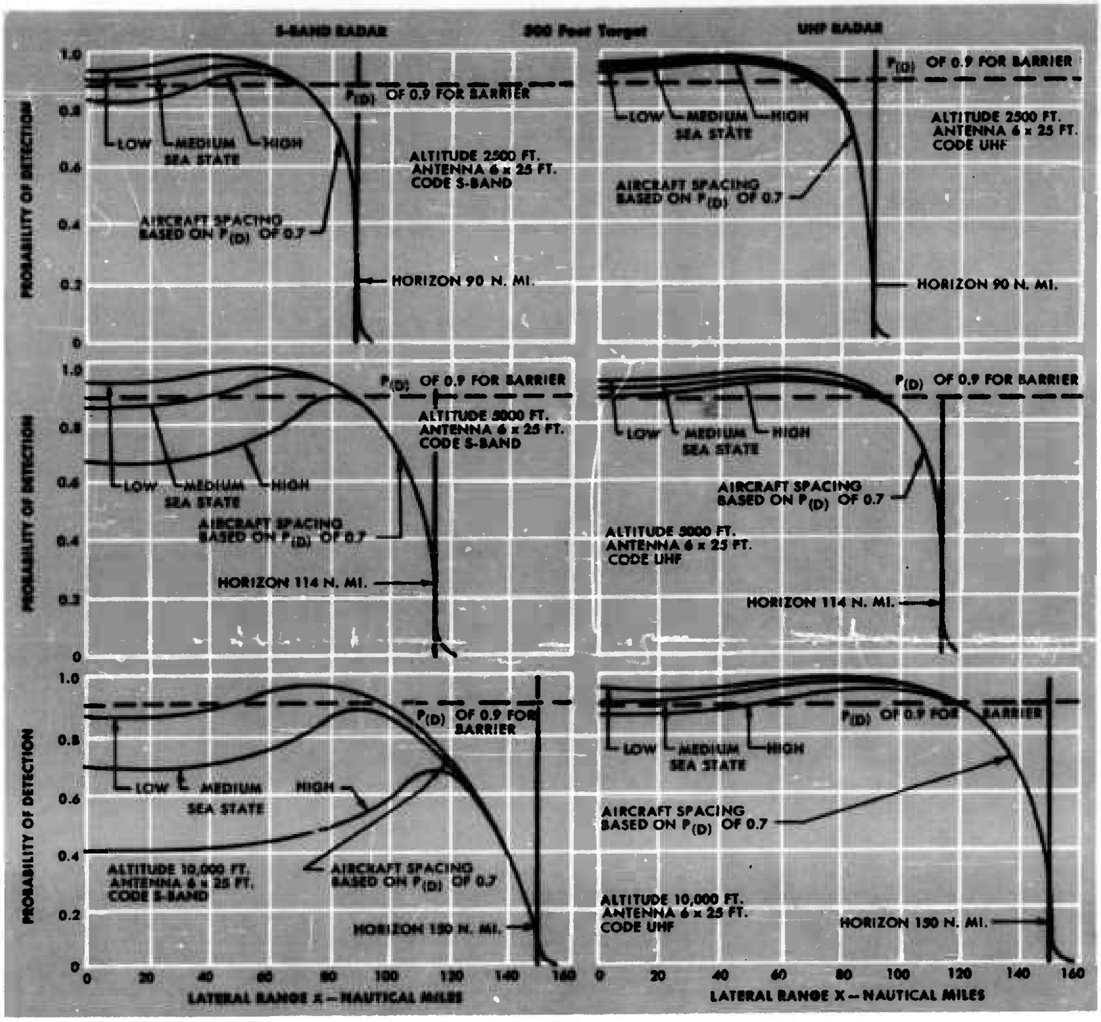

FIGURE A.4 — LATERAL RANGE CURVES

UHF radars. Similarly, an operator factor of .05 was used for this non-MTI case. Actually the selection of optimum aircraft is not greatly affected by these choices due to the range limitations imposed by the sea clutter and the horizon, i.e., the sea clutter circle expands with higher sea states and the horizon shrinks with lower flight altitudes. It is also apparent that even though the search radar may be horizon limited for low flying targets, larger

antennas provide better performance due to the more rapid build-up of the probabilities of detection within the detection annulus as well as for targets beyond the horizon at higher altitudes. As has been previously indicated, in Chapter II, the spacing of barrier aircraft is determined by the lateral range X where the probability of detection has decreased to a value of 0.7. This value of X is then multiplied by 1.0 to determine the operational spacing.

Under the conditions of high sea state, low flight altitudes, and horizon limitations the S-band or UHF radar system is selected which provides a probability of approximately 0.9 within the detection annulus. These selected systems provide a barrier spacing between aircraft of 165 nautical miles for S-band search radars and 208 nautical miles for UHF search radars.

REFRACTIVE ANOMALIES

The effects of refractive anomalies on search radar coverage are pronounced at times and are difficult to predict because of the insufficiency of statistical data covering the distribution of refractive anomalies, particularly in areas where barrier operations are being considered. Refractive anomalies may cause not only abnormal bending of the radar energy in space but if sufficiently intense, trapping in certain layers, and robbing energy from other areas, with resultant "holes" in the normal coverage pattern. This effect may be illustrated by ray diagrams as shown in Figure A.5. These figures are similar to those of Reference 43, and are based on information provided by Mr. M. S. Wong of the Wright Air Development Center. They show the effect of flying the aircraft above, below, and in a refractive layer of sufficient intensity to cause trapping of the rays.

Figure A.6 shows the ray diagrams of Figure A.5 replotted in more conventional form with similar conditions of refraction. These earth curvature coverage diagrams are typical of the data given in Reference 4 and serve to show the "holes" or areas of weak coverage as well as the extension of radar range due to trapping of energy in a refractive layer for targets flying at several altitudes.

43. *Interpreting Refractive Index Profiles in Terms of Radar Coverage*. Technical Paper No. 3. Air Defense Command Forecast Center, 3rd Weather Group, ENT Air Force Base. October 1953. (UNCLASSIFIED)

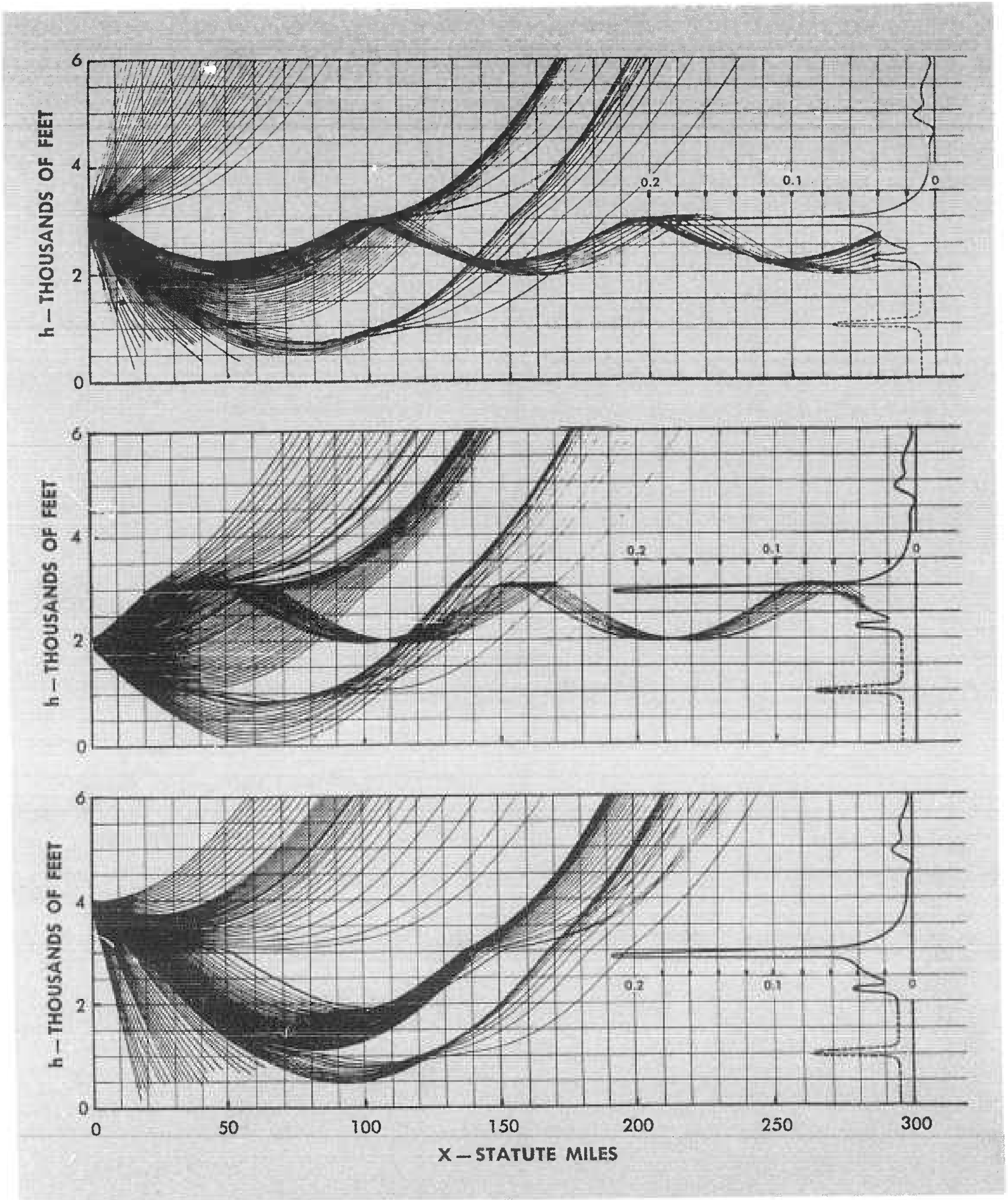

FIGURE A.5 – RAY PATHS VERSUS ALTITUDE AND RANGE

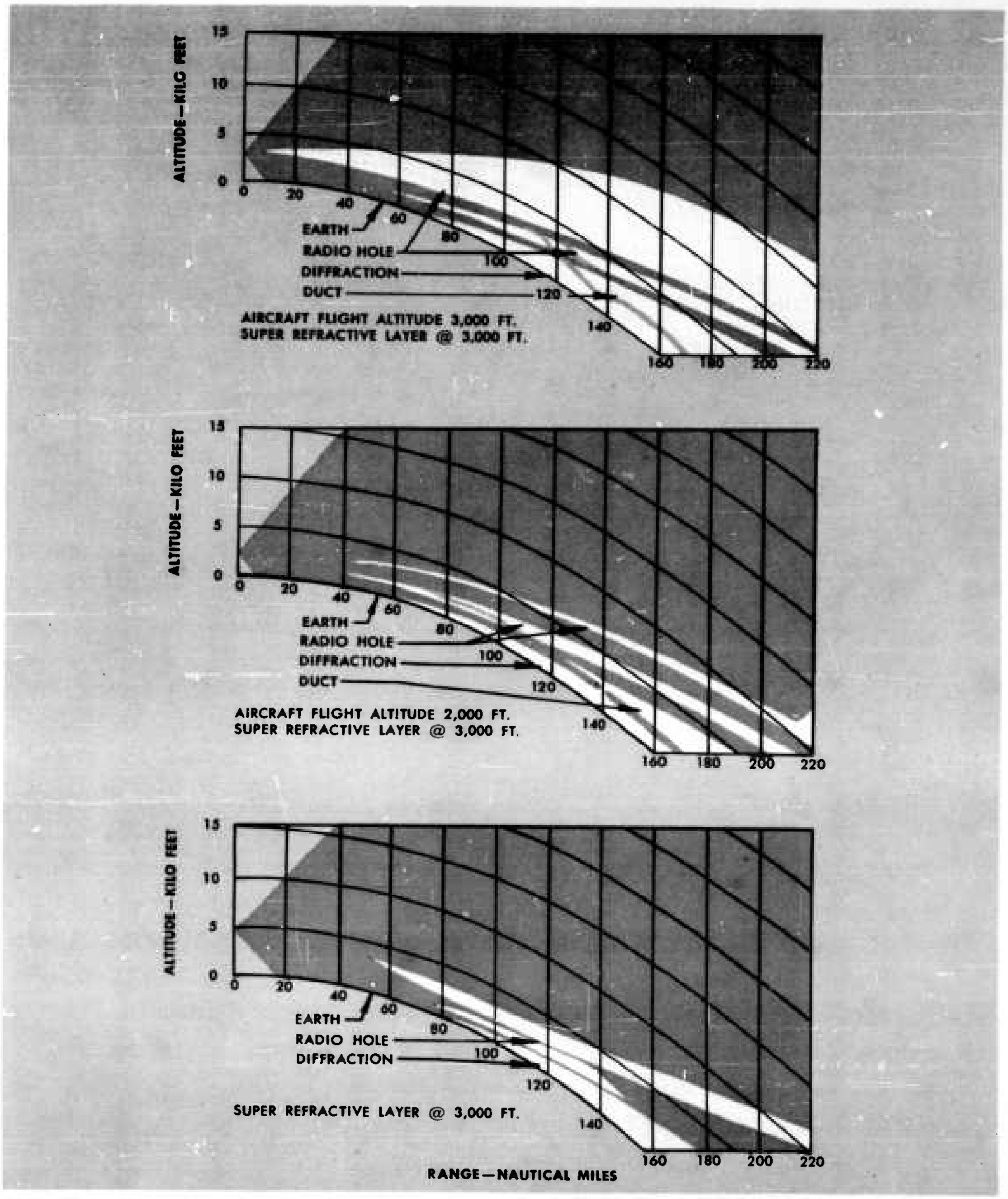

FIGURE A.6—TYPICAL RADAR COVERAGE DIAGRAMS

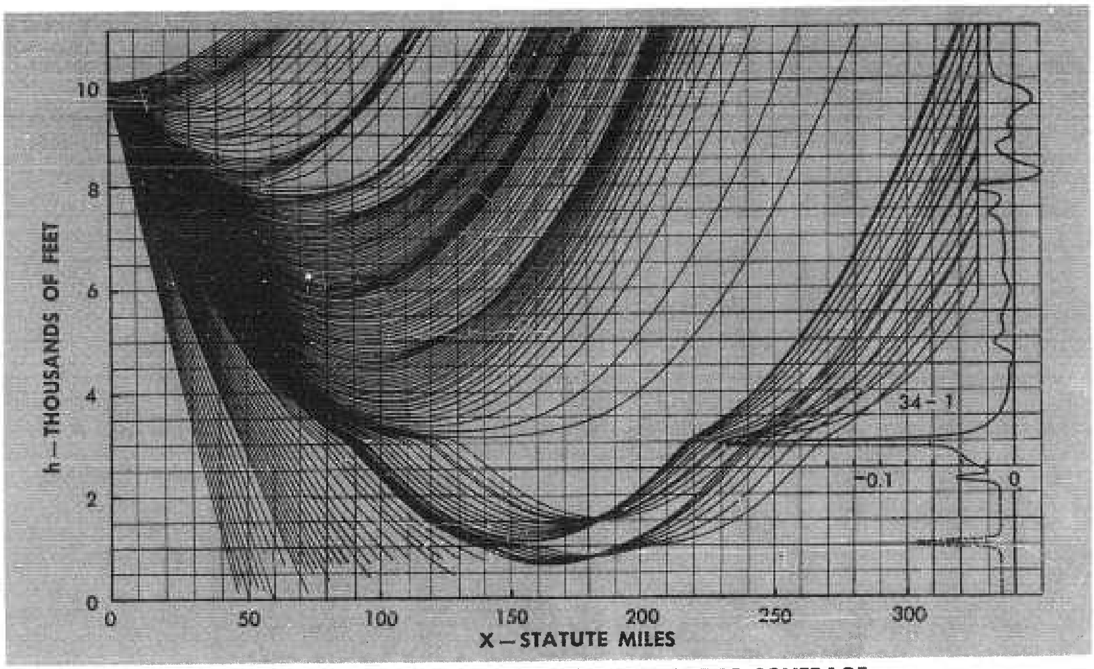

FIGURE A.7—a: RAY DISTRIBUTION AND RADAR COVERAGE

Figures A.7a and A.7b show the distribution of rays and radar coverage when the aircraft flight altitude is 10,000 feet. These diagrams clearly show the beneficial effects of flying above the altitudes at which refractive anomalies occur.

The frequency distribution of non-standard layers versus altitude taken from Reference 44 is shown in Figures A.7a and A.7b. These graphs show the results of over 4600 measurements taken on the East and West coasts and emphasizes the possible effects on radar coverage that may occur from multiple refractive layers when the flight altitude is determined by the extent of sea clutter. The "ideal" or so-called standard refraction condition of the atmosphere seldom occurs below an altitude of ten to fifteen thousand feet.

Most of the experimental tests described in References 45 and 16 to correlate the effects of non-standard atmosphere with propagation of radio

44. *Forecasting Refractive Index Profiles in the Atmosphere.* Technical Paper No. 2. Air Defense Command Forecast Center, 3rd Weather Group, ENT Air Force Base. September 1953. (UNCLASSIFIED)

45. Burrows and Atwood. *Radio Wave Propagation.* Consolidated Summary Technical Report of the N.D.R.C. Acadamic Press, Inc. 1949. (UNCLASSIFIED)

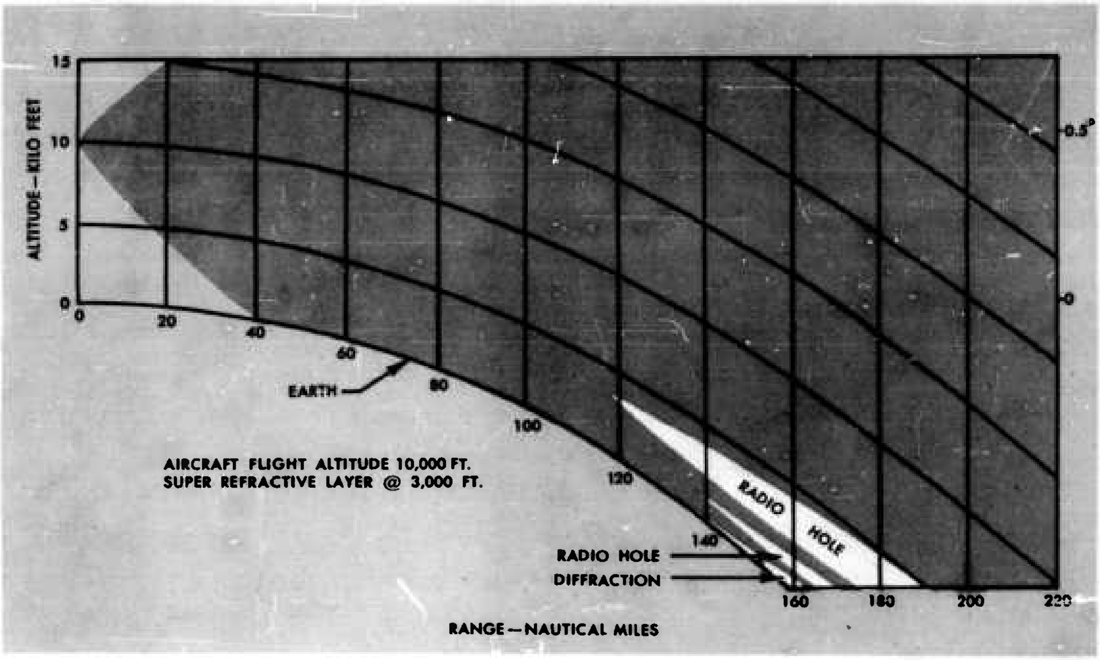

FIGURE A.7—b: TYPICAL RADAR COVERAGE

waves are based on one-way transmission paths, i.e., point-to-point radio communication. Search radar, on the other hand involves a two-way transmission path which would appear to make the effects of refractive anomalies more serious for the radar case. The holes in the coverage caused by bending or trapping of energy have usually been analyzed in terms of a free-space wave. In the case of longer wavelength radars, which can be expected to provide specular reflection even with high sea states, this reflected energy may tend to fill in the holes in the coverage, or at least make their effects less sharply defined. It is also possible that the bending due to refraction may change the phase and angle of arrival of the reflected energy in space, thus changing the lobe pattern in the interference region.

The important meteorological factors which may influence search radar coverage in DEW barrier operations are the following:

1. number of layers and their altitude distributions,
2. refractive gradients within the layers;
3. thickness of refractive layers,

4. geographical extent and area distributions,
5. tilt or slope of the layers with respect to the horizontal; and
6. layer discontinuities

Additional information is required covering the distributions of non-standard atmospheric conditions in order to better understand and cope with their effects on electro-magnetic wave propagation. See Figure A.8.

These distributions vary with time and are functions of latitude and season of the year. Most of the presently available data are based on measurements taken near land masses. Very little information is available covering the open ocean areas being considered for DEW barrier operations; however, the possible effects on the integrity of the line due to refractive anomalies in these more remote areas are considered serious.

It is apparent from the previous discussions that the flight altitude and barrier spacing of airborne search radar should be determined by sea state conditions. However, strong refractive layers may be formed in addition to high sea states following the passage of a storm. Under these conditions the absence of high winds is conducive to atmospheric stratifications of a super-refractive nature. Since the lower flight altitudes are determined by existing sea states the search aircraft may be flying in or near a refractive layer, thus compounding the difficulty of achieving high probabilities of detection. UHF radar has an advantage over S-band radar by being able to fly at a higher flight altitude for an equivalent sea clutter radius on the scope and may therefore be less affected by non-standard refraction.

In the absence of MTI, other methods so far proposed for reducing the effects of refractive anomalies, such as 1) increased effective radiated power; 2) altitude separation of aircraft above and below the anomaly; and 3) very close spacing of search aircraft, appear impractical. If effective MTI is successfully developed, the best way to reduce the effects of refractive anomalies is to fly high above the altitudes at which the anomalies occur. This technique will increase the radar coverage and reduce force requirements.

In view of the limitations which affect search radar without MTI it appears unlikely that practical DEW barriers can be established that will provide the desired level of detection under all conditions of the sea and atmos-

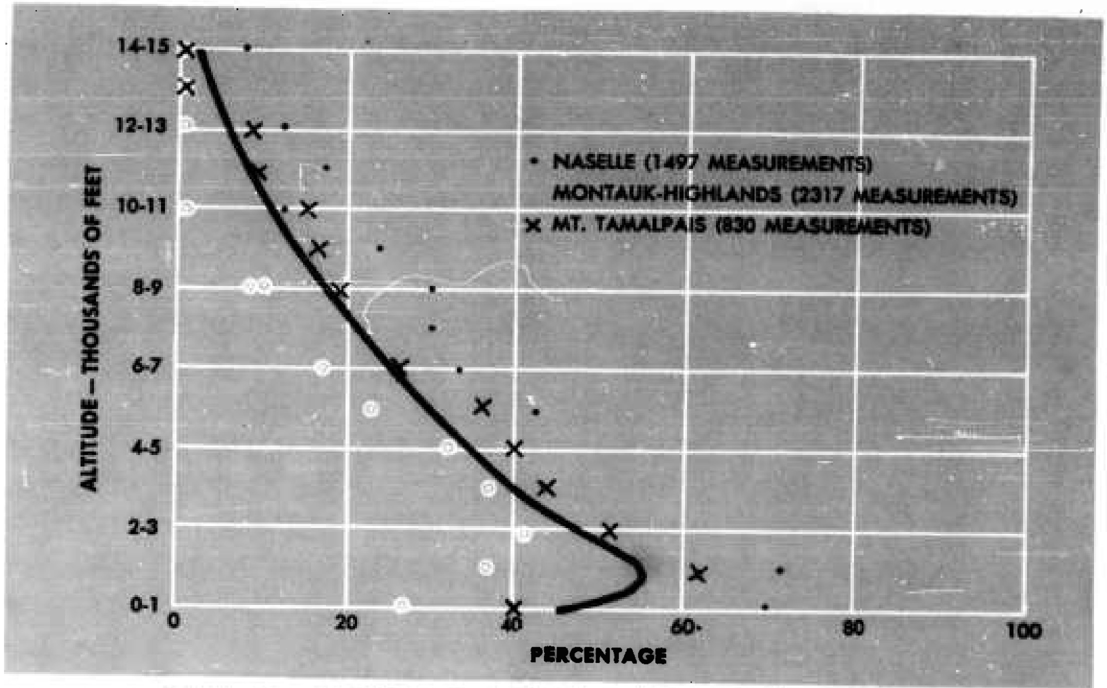

FIGURE A.8 — DISTRIBUTION OF REFRACTIVE ANOMALIES VS. ALTITUDE

phere. Nevertheless, the analysis has been carried through, ignoring the possible effects of the refractive anomalies on barrier system detection probabilities. In addition, since for the airplane and airship the addition of control equipment imposes small penalties, this function has been included even though it is of limited value without the development of MTI.

AIRPLANE ANALYSIS

The airplane parametric analysis for the non-MTI case closely parallels that discussed in Chapter V. A more limited range of parameter values is used, taking advantage of the experience gained in the first analysis. For example, the range of gross weight is reduced, and the number of barrier patterns is limited to two. As discussed previously, only those airplanes with a control capability are considered.

For the non-MTI case, it is necessary that the airplane fly at low altitudes. Consequently, since the turboprop is commonly considered to be at a disadvantage at these altitudes, both power plants were carried through

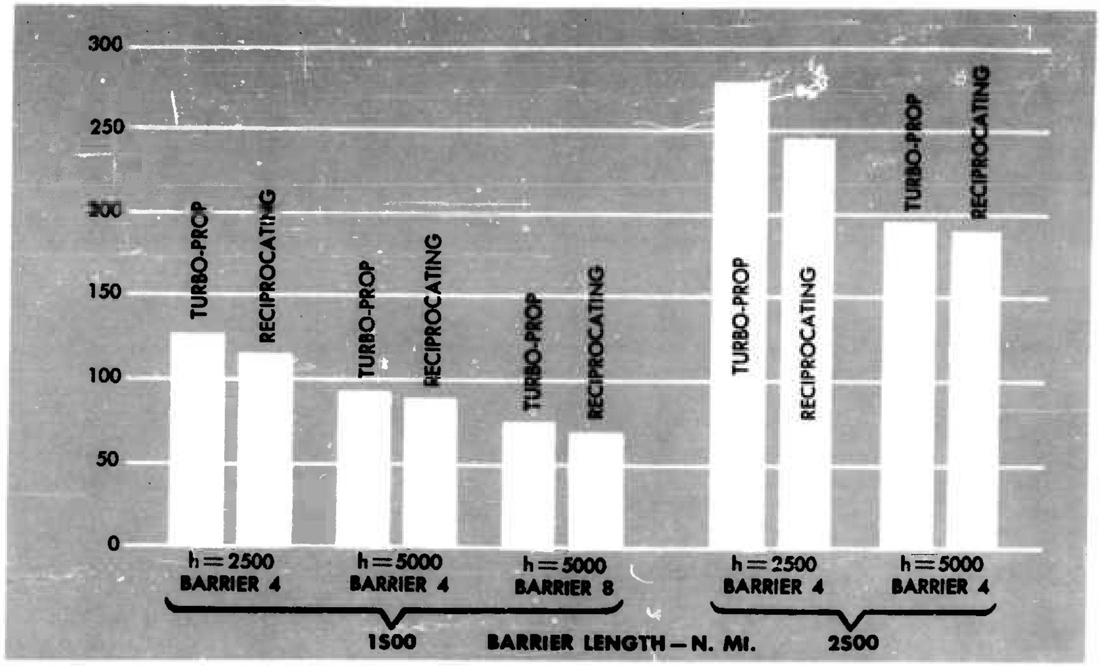

FIGURE A.9—EFFECT OF POWER PLANT ON SYSTEM COST

the analysis. As indicated in the radar performance analysis, altitudes of 2500 and 5000 feet were considered, with spacings of 165 and 208 miles respectively.

The more important results of the analysis are discussed in the following paragraphs.

<u>Power Plant Selection</u>

The power plant for the low altitude case is usually assumed to be a reciprocating engine. However, the parametric analysis results indicate that the reciprocating engine has very little advantage over the turboprop even at altitudes of 2500 feet.

Figure A.9 shows the system cost for various combinations of barrier length, altitude, and barrier pattern. In the majority of cases there is a difference of only a few per cent. As altitude increases, the turboprop becomes less expensive. In view of the very slight penalties paid for using the turboprop at low altitudes and the rather obvious advantage of growth potential for the turboprop configuration, no further consideration is given the reciprocating engine power plant.

Radome Size

In order to achieve the necessary probability of detection, the 6 X 25 foot antenna (6.3 X 31.5 radome) must be carried, as indicated by the values shown in Figure A.4. In addition, (cf. Chapter V), this antenna is also optimum for the high altitude case. The remaining discussion will be limited to airplanes carrying this size radome.

Speed

The range of speeds examined in the analysis was from 150 to 225 knots As in the previous analysis, the effect of increased speed is to increase the cost of the system. The lowest speed of 150 knots is always the least expensive.

Barrier Configuration

The fact that these barriers are flown at low altitudes does not alter the conclusion reached in Chapter V regarding the optimum barrier tactics. The optimum network consists of a pattern 4 for the 2500-mile barrier and a pattern 8 for the 1500-mile barrier.

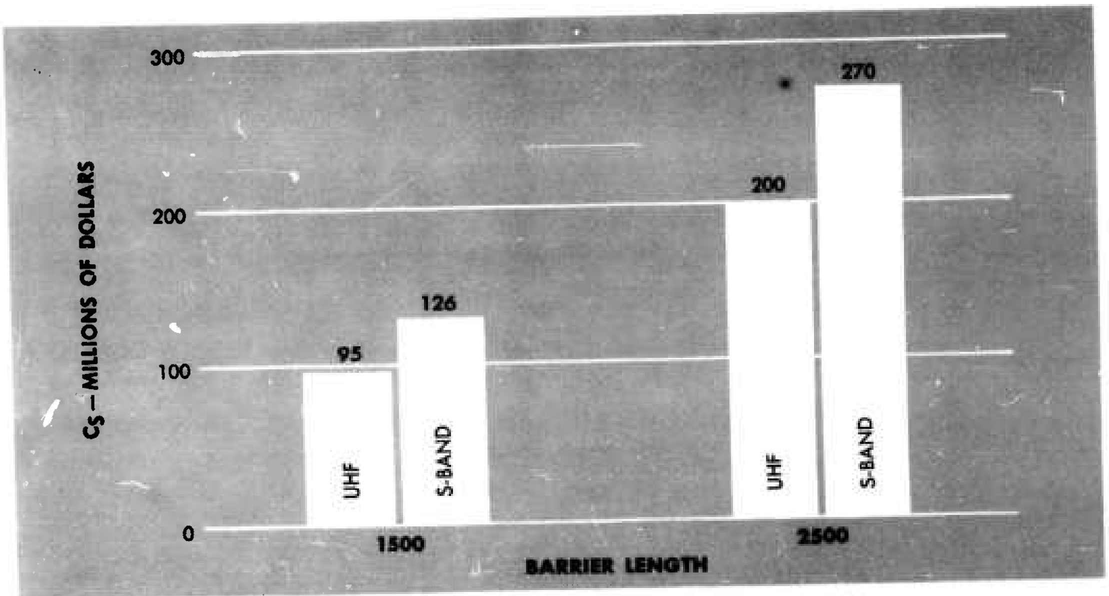

FIGURE A.10 — EFFECT OF RADAR TYPE NON-MTI CASE

Radar Type and Performance Level

The limitations on the altitude that may be flown with the non-MTI configuration restricts the spacing to values dictated by the sea state conditions and the horizon. The effect of radar performance level is not as influential as in the MTI situation since it does not appreciably change the spacing between aircraft.

The effect of radar type has a much greater effect on system cost than changes in performance level. Figure A.10 shows the costs for barriers in which UHF or S-band systems are employed. It is apparent that the inherent capability of the UHF radar to fly at higher altitudes for the same sea state conditions is a distinct advantage.

Selection of the Optimum Airplane

One of the most striking facts that becomes apparent from the analysis is the relatively large number of airplanes which are near optimum for a given set of conditions. For example, for a 2500-mile barrier, eight airplanes with widely different characteristics generate system costs varying by less than five per cent. The principal reason that no sharply defined optimum appears is that the large number of airplanes required in the system for the low altitude case tends to obscure differences in individual airplanes.

All of the aircraft that are near optimum have the following general characteristics:

1. Turboprop power plant

CHARACTERISTICS OF OPTIMUM AIRPLANES

BARRIER LENGTH (n. mi.)	1500	2500
BARRIER PATTERN	8	4
TAKE-OFF WEIGHT (lbs.)	110,000	130,000
ASPECT RATIO	12	12
WING LOADING (lbs./ft.^{2})	50	50
RANGE (at 5000 ft altitude)	2870	3440
VELOCITY (kts.)	150	150
AIRPLANE COST (millions of dollars)	4.19	4.65
NUMBER OF AIRPLANES	35	91
SYSTEM COST (millions of dollars/yr.)	75	199

FIGURE A.11

2. UHF radar
3. 6.3 X 31.5 foot radome
4. 150 knot cruise
5. Design flight altitude - 5000 feet

The specific characteristics of these two optimum aircraft are shown in Figure A.11.

The calculations for the selection of a single optimum for a network of the two barriers indicate that these two airplanes are also quite competitive in the network. However, the system using the 130,000-pound airplane is slightly less expensive. The 110,000-pound airplane is marginal from a range standpoint when used in the 1500-mile barrier pattern 8. In view of these considerations, the 130,000-pound airplane is indicated as the optimum airplane. The network system cost using this airplane is $279 million.

Use of MTI Optimum Airplane at Low Altitude

As indicated in Chapter V, the proposed optimum airplane for the high altitude case has a gross weight of 110,000 pounds and a range of 3220 miles at 35,000 feet. It is of interest to investigate the employment of this airplane in the non-MTI situation at the lower altitude. A range calculation was made for operating this airplane at 5000 feet and at a speed of 150 knots. The range of the airplane under these conditions is 2630 miles.

This range will not permit the airplane to fly the 1500-mile pattern 8 barrier unless a gap is accepted at the extremities. Assuming, for the sake of argument, enough extra range can be obtained in this airplane to permit the use of barrier pattern 8, the system cost for the network is slightly over 300 million dollars. Thus, the high altitude optimum pays a 7 to 8 per cent penalty when used at low altitudes.

Use of Non-MTI Optimum Airplane at High Altitude

The next logical comparison is that of using the airplane selected as optimum for low altitude, for the high altitude situation. It was determined that the 130,000-pound airplane has sufficient power to fly at 35,000 feet. Because of the aspect ratio and wing loading of this airplane, it must cruise at 250 knots to maintain stability. Under these flight conditions the range of the aircraft is 3900 miles.

The cost using the 110,000-pound DEW & C (cf. Chapter V) airplane in a DEW network is $131 million. Use of the low altitude optimum at high altitude results in a network cost of $132 million. Thus, the low altitude optimum pays practically no penalty when used at high altitude.

Summary

The information contained in the previous paragraphs is tabulated in Figure A.12.

The conclusion to be drawn from examination of these figures is that the low altitude optimum airplane should be selected for either condition. The airplane configuration is then independent of MTI development, but has the growth potential to permit exploitation of MTI developments. If development of MTI does not proceed satisfactorily the airplane is still optimum for the low altitude case.

NETWORK SYSTEM COST FOR HIGH AND LOW ALTITUDES
(MILLIONS OF DOLLARS)

	USED AT LOW ALTITUDE	USED AT HIGH ALTITUDE
LOW ALTITUDE OPTIMUM	279	132
HIGH ALTITUDE OPTIMUM	301	131

FIGURE A.12

HELICOPTER ANALYSIS

No separate parametric analysis was made for the helicopter without MTI. An examination of the proposed optimum helicopter at the lower altitudes was made and a near-optimum helicopter for low altitude operation is examined.

If the helicopter designed for 20,000 feet is used at the 5000-foot level, the endurance is nearly doubled. In addition, since the helicopter is considerably over-powered for this altitude only a short time is required to climb to altitude. The net result of these two effects is to decrease the number of helicopters required per station. However, the number of stations is increased because of the decrease in spacing. Thus, the over-all system cost increases.

The helicopter designed for an operating altitude of 5000 feet is somewhat smaller than the previous optimum. It is not necessary to examine it in any detail since the power plant is inadequate for the high altitude situation.

The cost figures for the usual network of barriers is shown in Figure A.13. These values indicate that the helicopter designed for the MTI case is nearly optimum for the non-MTI case. In addition, the Figure indicates that the change in system costs for the two cases is significant.

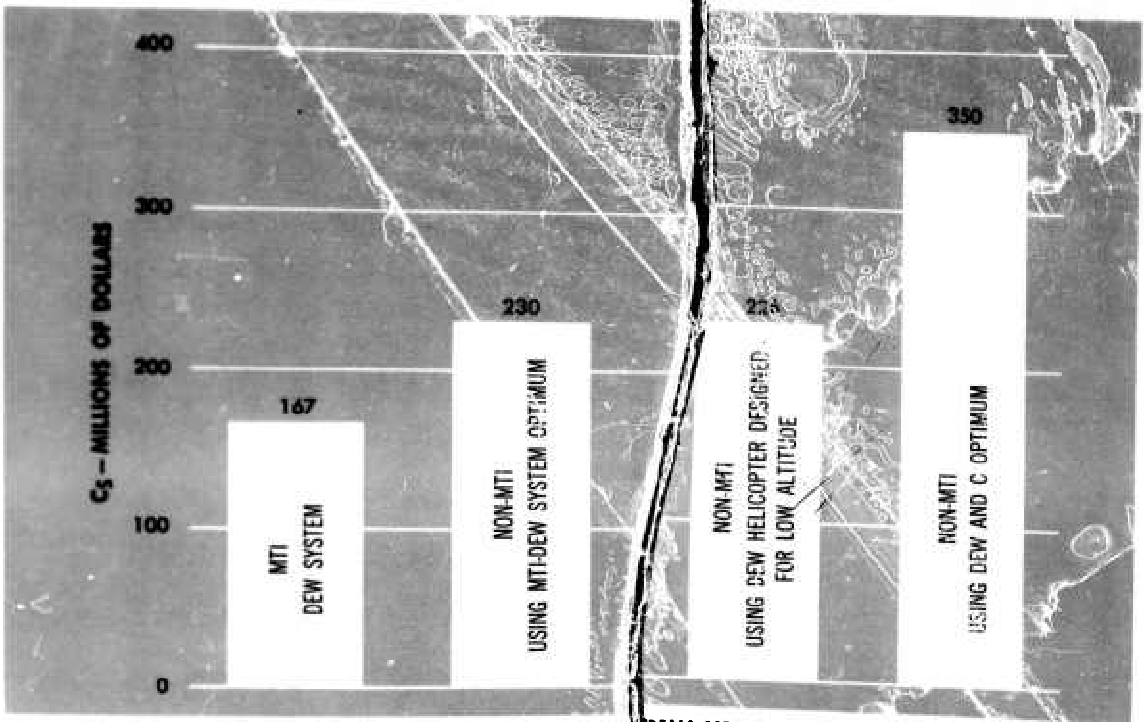

FIGURE A.13 — SYSTEM COSTS FOR DEW HELICOPTER BARRIERS

The fourth value shown in this Figure applies to the network using the DEW & C helicopter at the lower altitudes. The large difference in cost is due to the same influences discussed in Chapter VI; use of CVE instead of MV, larger crew, and larger helicopters.

These values clearly indicate the best course of action. It is apparent that the helicopter designed for the MTI case can be used at the lower altitudes with an insignificant penalty.

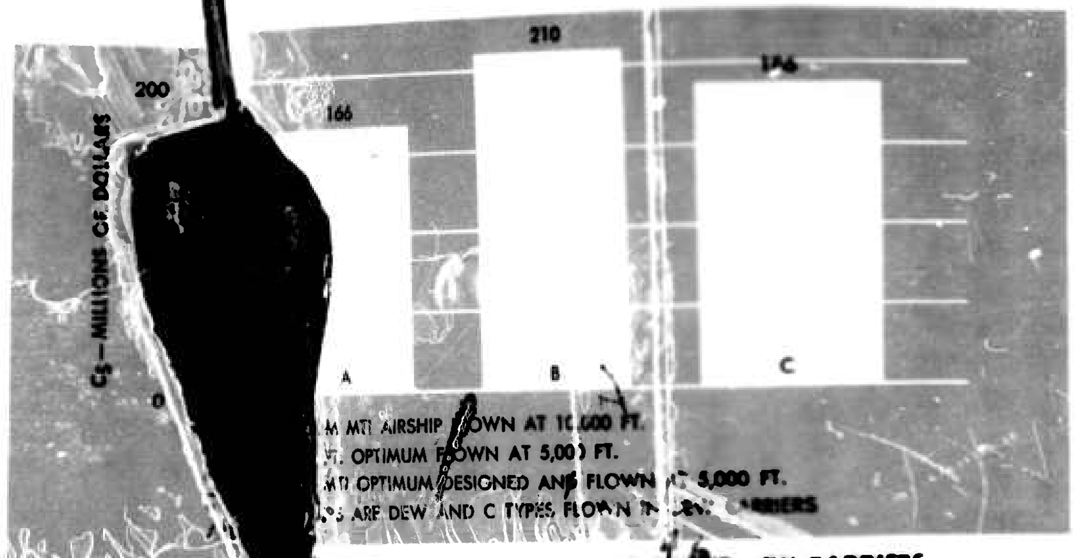

FIGURE A [illegible] SYSTEM COST FOR NETWORK OF A[illegible] DEW BARRIERS

AIRSHIP ANALYS[illegible]

A near-optimum [illegible]rship was calculated for operation at 5000 feet for the non-MTI situation [illegible] conditions and procedure explained in Chapter VII were used for th[illegible]lation.

The airship desi[illegible] for the 5000-foot case is somewhat smaller in volume than that for the [illegible]0,000-foot case, [illegible]t other characteristics remain essentially the same. [illegible]gure A.14 shows the network system costs for (1) the high altitude, (2) [illegible]e low altitude using the airship designed for high altitude and (3) the low a[illegible]de using the airship designed for low altitude.

One of the importa[illegible]s to notice is that the difference in altitude for the MTI and non-MTI c[illegible]r the airship is not great. Consequently, the difference in costs is not as [illegible]pparent as for the other aircraft systems.

An examination of the [illegible]re shows that rather important savings can be effected for the 5000-foot cas[illegible], if an airship is designed specifically for the task. If the 10,000-foot opti[illegible]um airship is flown at 5000 feet the penalty paid is slightly more than 10 [illegible]er cent compared to the optimum for 5000 feet.

The assessment of the [illegible]udy group is as follows. There are three factors which warrant the selecti[illegible] of the airship for operations at 10,000 feet: (1) advantage can be ta[illegible] of MTI when it is achieved, (2) even if MTI is not

achieved there are times in fair weather areas when operations at altitudes above 5000 feet are feasible, (3) it is desirable to operate as high above the refractive anomalies as is consistent with sea state conditions and the optimum altitude as indicated by the measure of effectiveness.

Therefore, the optimum airship is that designed for 10,000-foot altitude and has the characteristics indicated in Chapter VII.

COMPARISON OF THE NON-MTI SYSTEMS

The three vehicles have varying capabilities and are affected in different ways when used at 5000 feet. The relative positions of three vehicles are different than for the case assuming MTI development. When all three vehicles are forced to fly at the same altitude by the limitations of the sea state clutter circle the airship system becomes the least expensive. Figure A.15 is a composite of the values presented in the previous sections and shows the system cost for the network of a 1500-mile and a 2500-mile barrier. The three columns for each type are arranged from left to right to indicate system costs for (1) the aircraft designed for the MTI case and flown at the design altitude (2) the aircraft designed for high altitude and used for the non-MTI

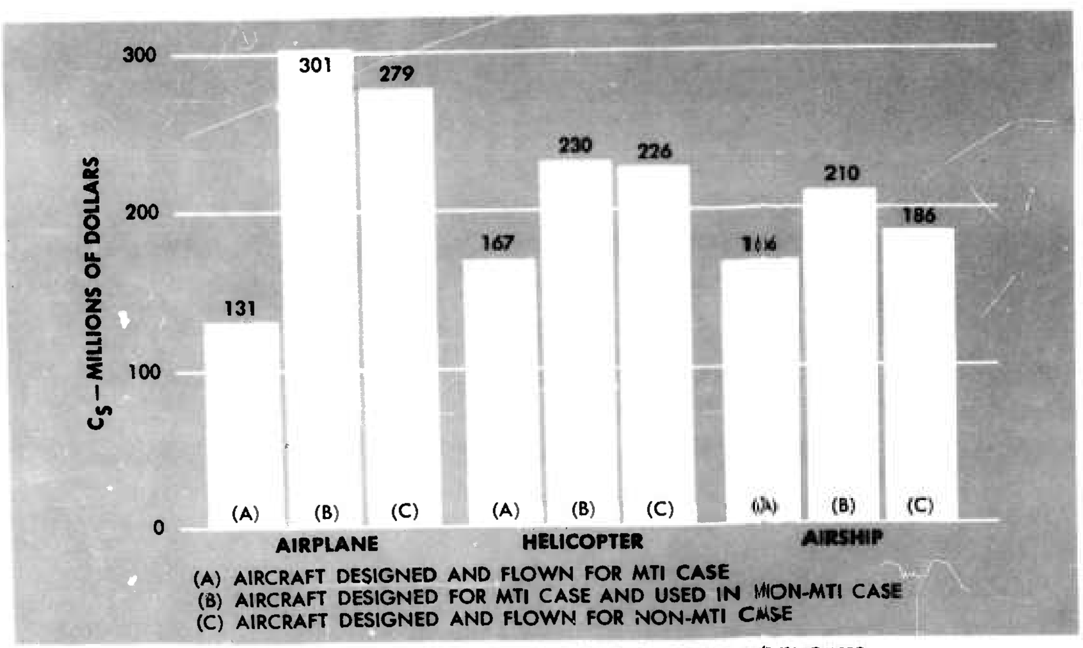

FIGURE A.15 — SYSTEMS COSTS FOR BARRIER NETWORKS

case (3) the aircraft designed and flown for the non-MTI case. The airplane and airship are configured with a DEW & C capability. However, the helicopter system is shown for the DEW configuration since the DEW & C configuration is not competitive at any altitude. It is seen that for the non-MTI case, the airship is the least expensive even when using the non-optimum design. The airplane becomes significantly more expensive if it is forced to fly at the lower altitude.

RECAPITULATION

If effective MTI search radar systems are not achieved, distant early warning systems will be seriously compromised by sea clutter and refractive anomalies. Some of the more important results generated by this deficiency are listed below.

1. Search radar without MTI cannot provide high probabilities of detection of air targets at all altitudes. A great deal more statistical data will be required concerning the vertical and horizontal distribution of refractive anomalies in order to determine their effect on search and control radar systems flying at low altitudes in areas being considered for distant early warning and control barriers.

2. In-flight force requirements are a function of weather and other factors, hence larger force requirements may be needed at times to overcome the adverse effects of the sea and atmosphere.

3. UHF radar is superior to S-band radar and requires fewer aircraft for a given level of detection. In addition, UHF radar may be superior to S-band radar in terms of filling-in by specular reflection the holes in coverage caused by refractive anomalies.

4. Airborne search and control systems cannot provide a useful control capability except in the limited areas in and adjacent to the clutter-free detection annulus.

5. The optimum airplane for the low altitude non-MTI case is somewhat larger than for the MTI case. The non-MTI airplane can be used at high altitudes and is near optimum for this altitude. It appears that an airplane can be designed that is independent of MTI development.

In order to allow for growth, the airplane selected should be configured with turboprop power plant and a 6.3 X 31.5 foot radome.

6. The airship selected is sensitive to development of MTI. Considerably different airships are required for the two different altitudes.

7. The helicopter selected is also insensitive to MTI development. In contrast to the airplane, however, the MTI optimum should be selected.

8. It is apparent that strong emphasis should be placed on development of a satisfactory MTI system for the UHF radar.

APPENDIX B
REFUELING IN EARLY WARNING BARRIERS

POSSIBILITIES IN REFUELING TECHNIQUES

This appendix discusses the application of refueling techniques to early warning barriers. An examination is made of the feasibility of reducing DEW system costs by extending the range capability of the early warning aircraft.

Certain important possibilities resulting from development of such a capability are apparent. These are:

1. To use short-range airplanes in long (2500-mile) barriers,
2. to extend the range of aircraft used in orbiting-type barriers,
3. to permit the use of airplanes of lower gross to carry out assigned tasks.

The optimum DEW & C airplane (see Chapter V and Appendix A of this report) is selected as a basis for discussion. This airplane has a take-off weight of 130,000 pounds and a range of 3900 miles. The larger size of the airplane and the increased time-on-station gained by refueling permits an increase of crew size so that EW missions up to 24 hours in length can be flown by this EW & C airplane. The three important potential advantages are briefly evaluated in the following paragraphs:

1. As noted in the body of the report, although barrier 8 requires the least number of airplanes, the range requirements for longer barriers dictate a large airplane. The optimum DEW & C airplane with a range of 3900 miles can be used in pattern 8 when barriers are no more than approximately 2200 miles in length, but its range is inadequate if the barriers are longer. Refueling this airplane at some point along the barrier increases its range capability so that it can fly the longer barrier.

2. Since the number of airplanes required for the orbiting-type barrier is range-dependent an increase in range, such as that offered by refueling, will increase the number of search airplanes required. The most important

application of this extension of range-capability is that barriers may be established which otherwise cannot be flown. For example, if a base cannot be established at one end of a barrier, the larger airplane is required. Pattern 6, for a 2500-mile barrier, is an example of this situation. Refueling permits the use of an optimum airplane in a pattern 6 barrier. The third possibility is that over-all system costs might be reduced by using a search airplane smaller than the selected optimum and extending its range as necessary by refueling. This is investigated by means of calculations for an airplane of 90,000-pounds, and one of 110,000-pounds, gross weight. The 90,000-pound airplane was determined to be near the lowest practical size to carry the crew and equipment required. The steps taken to determine this minimum-sized airplane were:

1. Designs of comparable types were examined with attention to dimensions and equipment layout.
2. An empirical formula was developed to approximate the fuselage volume to accommodate given areas occupied by major items of military load.
3. The applicable items of equipment for the EW(C) airplane were tabulated, with estimated area requirements. This furnished a value for solving the formula referred to in (2) above.

Consideration of the advantages discussed limits the study to early warning only and to barrier patterns 4, 6 and 8. A network composed of 2500-mile and 1500-mile barriers is used as the basis of comparison.

There are certain disadvantages in adding tankers to the system. Some degradation of the EW barrier results from refueling. It may be necessary to interrupt radar search and perhaps communications during the refueling process, although this matter is not considered too serious since all the fuel required can be transferred in less than 5 minutes.

Another possible degradation has greater implications. This is the problem of tanker abort, or failure to make refueling rendezvous, which has the effect of causing an abort of the search plane (or planes) in question. In most cases the system can be failsafe for the DEW plane. In one case an unrefueled plane could not reach a base at the end of the barriers, and would be forced to ditch. In any event, a serious lapse in barrier effectiveness would occur, and this risk must be accepted in any system that depends on tankers.

ASSUMPTIONS

The study is based on the following assumptions:

1. The spacing between aircraft is for a radar performance level one.
2. The weight addition for plumbing to receive fuel (about 200 pounds (see Reference 46) and for additional crew members is small and can be compensated for by slight adjustments to the refueling schedule.
3. The tanker design is compatible with that of the early warning type. This is to ensure that the aircraft can make contact and deliver fuel without any departure from station by the early warning aircraft.
4. Utilization factors for both the tanker and EW plane are identical.

DISCUSSION

Scope

The determination of an optimum DEW plane-tanker combination might generate a new optimum design for both the early warning and tanker configurations. Time limitation did not permit an extensive analysis of this type. Consequently, the decision was made to superimpose refueling on certain barrier systems using the optimum early warning aircraft as proposed in Chapter V of this report. In addition, smaller airplanes are examined in a barrier network.

Two tanker types were selected as representative of those that might be used.

The general characteristics are:

	Jet Type	Turboprop Type
Gross weight, lbs.	361,000	175,000
Cruise speed, kts.	460	280
Total fuel at take-off	219,000	79,000

The tanker that appears to perform most efficiently is costed in each barrier combination examined.

Determination of tanker force requirements is made by a series of successive approximations. With any given set of conditions the paths of EW planes in the barrier must be laid out and then various tanker patterns fitted in. There is usually a compromise between the number of refuelings

46. Design of Receiver Aircraft Installation for In-Flight Refueling. Boeing Report 10302, 1950. (UNCLASSIFIED)

that can be accomplished on a single tanker mission, and the minimum distance it must carry the fuel. In some cases there is a choice of refueling a single plane once or twice. There also may be a choice between basing all tankers at one end of the barrier or dividing them between two bases. These possibilities were explored in all the barriers in question. A typical result is indicated in Figure B.1.

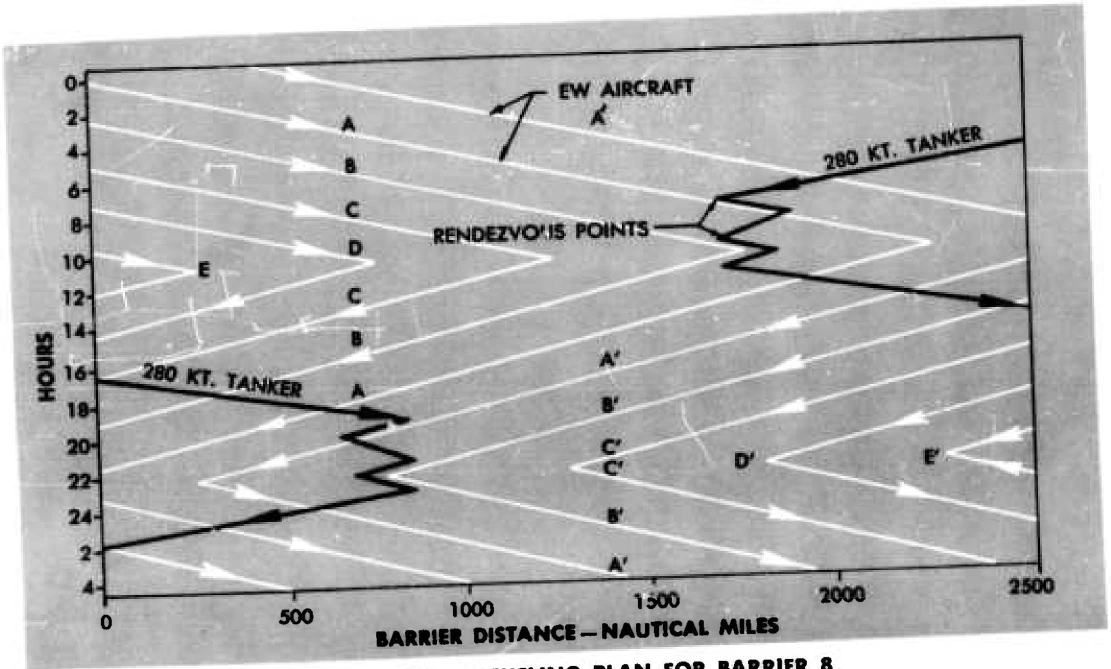

FIGURE B.1 — REFUELING PLAN FOR BARRIER 8

Having determined the best mission time of the tanker and the number of missions required in each case a simple computation produced the force requirement. Using similar formulas to those employed in the basic study, costs were determined for each of the 2500-mile barriers using refueling. All the aircraft under consideration have the capability of flying the 1500-mile number 8 barrier without refueling. The costs for the 1500- and 2500-mile barriers were combined to obtain the values required for comparison. Figure B.2 summarizes the results of the calculations.

COMPARISON OF DEW BARRIER NETWORKS WITH AND WITHOUT REFUELING

CASE	AIRPLANE TAKE-OFF WEIGHT (lbs.)	BARRIER LENGTH	BARRIER PATTERN	REFUEL	NUMBER OF DEW AIRPLANES	NUMBER OF TANKERS	ANNUAL SYSTEM COST (millions)	ANNUAL NETWORK COST
A	130,000	2500	4	NO	36.0	NONE	83.2	132.2
		1500	8	NO	14.7	NONE	49.0	
B	130,000	2500	8	YES	25.0	2	69.4	118.4
		1500	8	NO	14.7	NONE	49.0	
C	130,000	2500	4	YES	29.8	5.1	88.7	137.7
		1500	8	NO	14.7	NONE	49.0	
D	130,000	2500	6	YES	47.0	10.5	153.1	202.1
		1500	8	NO	14.7	NONE	49.0	
E	220,000	2500	6	NO	53.8	NONE	188.4	255.6
		1500	8	NO	14.7	NONE	67.2	
F	110,000	2500	8	YES	25.0	4.0	73.4	120.8
		1500	8	NO	14.7	NONE	47.4	
G	90,000	2500	8	YES	25.0	5.1	74.0	119.0*
		1500	8	NO	14.7	NONE	45.0	

* FOR THIS SYSTEM, IF RENDEZVOUS FAILURES OCCUR, SYSTEM COSTS WILL INCREASE.

FIGURE B.2

Results

Case A in Figure B.2 is taken directly from the main body of the report and is the basis for the following comparisons.

In Case B, refueling is employed to permit use of pattern 8 in the 2500-mile barrier. The number of early warning aircraft required is reduced from 36 to 25 with the addition of only two refueling aircraft. The net result is a saving of 14 million dollars in the network.

In Cases C and D the effect on orbiting pattern is examined. In Case C, the increased range obtained by refueling in the 2500-mile barrier results in a saving of only 6 EW airplanes and requires 5 tankers to operate the system. Instead of decreasing the cost of the system, the cost is increased by over 5 million dollars. In Case D, pattern 6, another orbiting pattern is examined. As can be seen, the number of tankers and EW aircraft is increased materially and network cost jumps to 202.1. Case E is shown for comparative purposes and indicates the size of airplane that must be selected if pattern

6 is flown without refueling. If it becomes necessary to use a one-base system, refueling provides a method of establishing a barrier, although it is admittedly expensive.

Finally, the advantages of using a smaller airplane than the optimum is shown in Cases F and G. The use of the 110,000- or 90,000-pound airplane in the 2500-mile barriers results in decreasing the network cost as compared to case A by approximately 11 to 13 million. However, compared to Case B, there is no saving.

In no case was the jet tanker found to be more economical than the smaller turboprop type. This was because of the very high cost and fuel consumption of the jet type, and little appreciable saving in force requirement.

The failsafe feature is apparent in all of the barriers studied except one. This is barrier 8, using the 90,000-pound airplane. The cost of a system which is not failsafe would be increased by the increased attrition rate. This increase in attrition rate would be the result of the loss of aircraft if a rendezvous failure occurs. It is apparent then that a system that is not inherently failsafe is somewhat more costly than a comparable failsafe system.

SUMMARY

1. Use of tankers allows the optimum airplane to fly the optimum barrier, number 8, at a network saving of about 10 per cent compared with the unrefueled optimum.

2. If barrier 4 is used instead of barrier 8, the network becomes some 4 per cent more expensive than the non-refueling case.

3. If a smaller than optimum airplane is used in the network, there is no saving as compared to the use of the refueled 130,000-pound optimum.

4. If only a single base can be used for the 2500-mile barrier 6, the network cost will exceed the optimum by approximately 50 per cent.

5. If only a single base can be used for the 2500-mile barrier 6, the refueling techniques results in a network that is about 20 per cent less expensive than designing an optimum aircraft for this situation.

6. Refueling does not offer any significant advantage in the case of the systems examined but it adds complexity to the system. The major advantage appears to be that it permits flying barriers that cannot otherwise be flown.

APPENDIX C
COMBINATION SHIP-AIRPLANE BARRIERS

This appendix discusses the use of combination ship-airplane barriers. As stated in the assumptions, the main body of this report concerns itself with pure systems. If ships are included in the system, they are considered to be for communication relay or navigation purposes. While they provide redundant radar coverage, they are not relied upon to change the number of aircraft required. The possibility of reducing the number of aircraft required by taking advantage of the radar coverage of the picket ship is examined. In addition, the navigation and communication contributions of the picket ships are examined.

GENERAL

An examination of the various barrier patterns quickly shows that certain methods of employment are required for combination barriers. The pipeline method of employment is not adaptable to a combination barrier. The spacings between aircraft continuously moving along the barrier cannot be increased without introducing a moving gap in the barrier. The probability of detection of the barrier will then drop below the 0.9 used as the criteria in this study. This is true even though there are ships in the barrier, unless high altitude targets only are considered.

The bump or shift methods appear to be adaptable to combination barriers. In this type of employment, the aircraft orbits around a geographical point; and since this will define an area of radar coverage, the ships can be placed as gap fillers between adjacent stations. Figure C.1 illustrates the resulting coverage. The bump technique as explained in Chapter IV can be used without modification. The shift method must be modified if unbroken radar coverage is to be maintained. This modification is designated as the "ripple-shift" method. In this technique, the airplane at Station 1, when relieved, moves toward Station 2. When the radar coverage circles overlap as indicated by the dotted circle in Figure C.1, the airplane in Station 2 starts movement toward Station 3. Thus, during the shift movement, no dependence is placed on the ship radar for maintaining the integrity of the barrier.

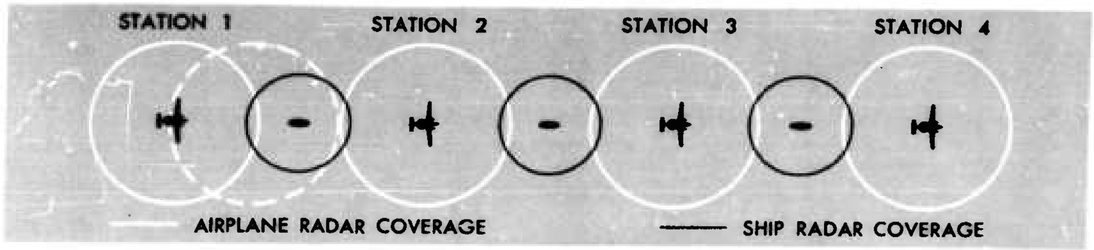

FIGURE C.1 — USE OF PICKET SHIPS AS GAP FILLERS

Using the basic formula for force requirements, the number of aircraft required for the ripple shift method is:

$$N = \emptyset\left(\frac{D + S_1}{S + S_1}\right)\left(\frac{1}{1 - \frac{D}{2R}}\right)$$

where:

S_1 = Diameter of ship radar coverage

An examination of barriers using the bump method indicated that more airplanes are required than for the ripple shift method. This method is dropped from further consideration.

ASSUMPTIONS

The following general assumptions are made:

1. The picket ship considered is the DER type, and is equipped with the AN/SPS-6B air search radar.
2. Back-up factors for the ship are 0.67 and 2.0.
3. The DER will not break the integrity of the line to conduct ASW.
4. Radio and radar propagation follows standard conditions. Standard atmospheric conditions are assumed for radio and radar propagation.
5. The airplane considered is the optimum DEW & C airplane.
6. Airplanes and ships are spaced alternately.

RADAR CONSIDERATIONS

As is apparent, the major limitation for the picket ship air search radar is the horizon limitation. Using the assumption that the target flies at 500

feet and that the ship radar antenna is at 50 feet, the lateral range for a 0.7 probability of detection is approximately 30 miles. The ship radar level of performance has little effect on lateral range at low altitude. For the airplane, however, the two levels of radar performance are considered.

FORCE REQUIREMENTS

Force requirements are rounded out to the nearest whole number after calculation, using the equation. Figure C.2 tabulates the force requirements for the conditions listed above.

BARRIER FORCE REQUIREMENTS

	BARRIER LENGTH	1500		2500	
	RADAR PERFORMANCE	1	2	1	2
AIRPLANES	PURE SYSTEM SHIFT METHOD	18	24	36	46
AIRPLANES	COMBINATION BARRIER RIPPLE SHIFT METHOD	17	21	33	41
SHIPS	FORCE REQUIREMENT 0.67 BACKUP	4	5	6	9
SHIPS	FORCE REQUIREMENT 2.0 BACKUP	7	9	12	15

FIGURE C.2

It can be seen that the saving in aircraft for the shorter barrier and for the high level of radar performance is insignificant. As the radar performance changes to level 2 and the barrier length increases, small savings in numbers of aircraft are obtained. It should be noted that the number of ships required is always more than the number of airplanes saved, even for the low back-up factor. This in itself indicates that combination barriers are inefficient if employed against low-altitude targets.

COSTS

The procedure for determining the costs of the airplane portion of the combination barrier is the same as that used in Chapter V. The ship costs used are obtained from References 29 and 30. As shown in the references, the cost for a DE is 0.11 million per month. Recent figures received from

CNO indicates a monthly cost for a DER of 0.12 million. The costs shown in the references are based on a back-up factor of 0.67. More recent discussions have indicated that a back-up factor of two may be required for the radar pickets.

Using the cost figures as indicated, the annual cost of maintaining a network of two barriers 1500 and 2500 miles in length is calculated.

Figure C.3 shows the component and total cost of the pure and combination barriers for the various conditions assumed. It should be noted that the pure systems computed here are for pattern 4 barriers. The optimum combination, as shown in previous chapters, is a barrier pattern 4 for the 2500-mile barrier and a barrier pattern 8 for the 1500-mile barrier. Figure C.4 shows in bar chart form the information given in Figure C.3 with, in addition, the optimum network cost.

It is clear from Figures C.3 and C.4 that the addition of ships to the barrier does not result in any significant savings. In fact, if the ship costs are charged against the barrier the resulting system costs are increased by as much as 20 per cent.

NAVIGATION AND COMMUNICATIONS

The addition of picket ships to the barrier has often been proposed to increase the reliability and efficiency of communications and navigation. The model proposed for the combination barrier has several disadvantages when considered from the standpoint of communications and navigation.

The optimum airplane is designed to fly at 35,000 feet even though radar performance level 2 requires an altitude of only 29,000 feet. If the communication antennas on the DER are assumed to be at an average height of 45 feet the radio line-of-sight distance is approximately 238 miles. For performance level 1, when the ship and the airplane are at their on-station positions, the distance between them is 275 miles. Therefore, reliable UHF communication between the ship and the airplane cannot be maintained since they are separated by more than the line-of-sight distance.

If a radar performance level 2 is encountered, the distance between the ship and airplane is nominally 221 miles. Here the two stations are within line-of-sight distance and, subject to the usual limitations of UHF communications at long distances, can maintain communications. For both radar

COST OF PURE AND COMBINATION BARRIERS

RADAR PERFORMANCE LEVEL	BARRIER LENGTH	SHIP BACKUP FACTOR	NUMBER SHIPS REQUIRED	NUMBER AIRPLANES REQUIRED	C/N	TOTAL AIRPLANE COST	BASE COST	SHIP COST	TOTAL SYSTEM COST	NETWORK COST
PURE AIRPLANE SYSTEM										
1	1500	—	—	18	1.59	28.6	26.0	—	54.6	
1	2500	—	—	36	1.59	57.2	26.0	—	83.2	137.8
2	1500	—	—	24	1.59	38.2	26.0	—	64.2	
2	2500	—	—	46	1.59	73.2	30.0	—	103.2	167.4
SHIP—AIRPLANE SYSTEM										
1	1500	0.67	4	17	1.59	27.0	26.0	5.7	58.7	
1	2500	0.67	6	33	1.59	52.5	26.0	8.7	87.2	145.9
2	150	0.67	5	21	1.59	33.4	26.0	7.2	66.6	
2	2500	0.67	9	41	1.59	65.3	26.7	13.0	105.0	171.6
1	1500	2.0	7	17	1.59	27.0	26.0	10.1	63.1	
1	2500	2.0	12	33	1.59	52.5	26.0	17.3	95.8	158.9
2	2500	2.0	9	21	1.59	33.4	26.0	13.0	72.4	
2	1500	2.0	15	41	1.59	65.3	26.7	21.6	113.6	186.0

FIGURE C.3

performance levels, some type of on station orbiting pattern will be flown. Such a pattern may provide intermittent communications for the level 1 situation and increased reliability for the level 2 case.

The use of the picket ship as a navigational check point requires that it be within radar range of the airplane. With the airplane at 35,000 feet, the radio line-of-sight to the surface ship is 230 miles. If the aircraft are spaced for performance level 1, the picket ship is beyond the line-of-sight and cannot be used as a navigational aid. If the spacing is for level 2, the picket ship is within radar range and can be used as a navigation reference. The use of a picket ship as a navigational aid presumes, of course, that it

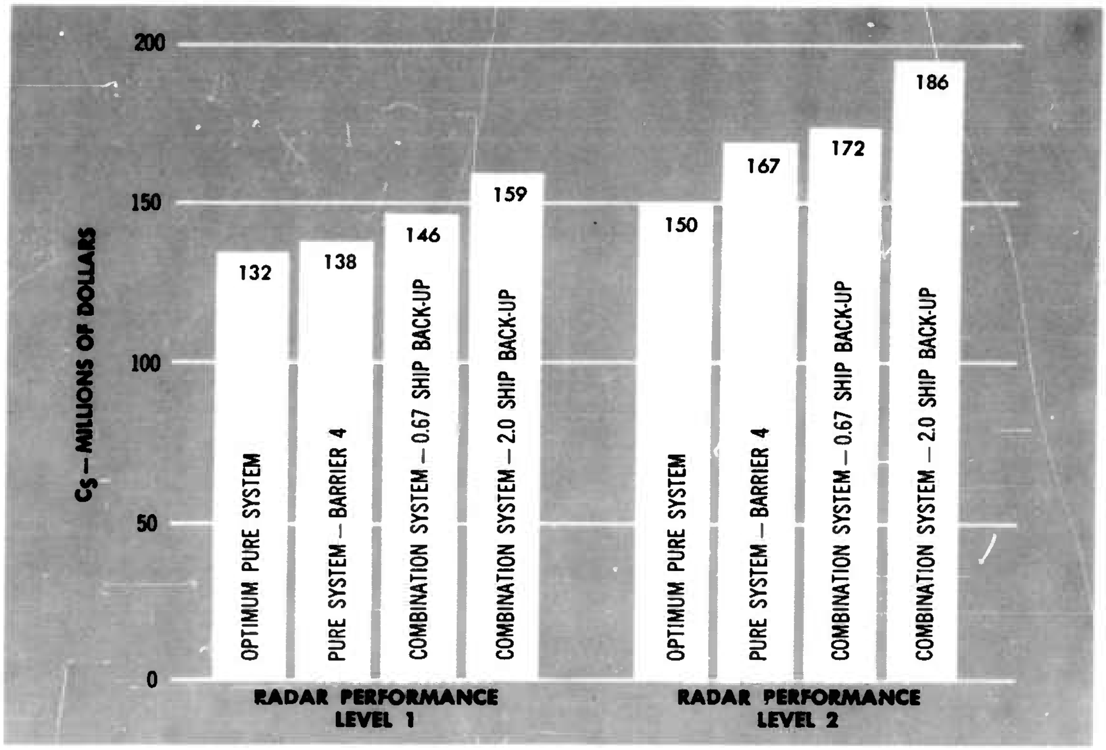

FIGURE C.4 — COST OF PURE AND COMBINATION BARRIER NETWORKS

can determine its position more accurately than can the airplane. During periods of heavy weather and low visibility where the ship may be forced to rely on ded reckoning, such a presumption is not necessarily valid. For all of these cases, as the airplane moves from station to station during the shift process, communication and navigation functions can be accomplished as the airplane passes the picket ship.

AIRPLANE-SHIP DEW & C BARRIER

The pipeline is the method of employment used in DEW & C barrier. For this situation, the addition of picket ships has no effect on the airplane force requirement. The ships would provide some redundancy in radar coverage and could possibly be used to aid in controlling kill weapons. To insure a high degree of reliability, ships should be spaced approximately 475 to 500 miles apart, if the optimum airplane is used. The airplanes may

be spaced closer than this for control coverage, but no airplane will be out of communication with the pickets for more than a few minutes. Of course, fewer ships could be used, but this would increase the period of time during which the aircraft are not in communication. Briefly, then, the presence of ships in the DEW & C barrier would increase the barrier cost without any decrease in airplane force requirements.

SUMMARY

To summarize, this analysis results in the following:

1. Combination ship-airplane barriers must utilize the orbiting patterns in order to reduce the number of aircraft required.
2. The number of aircraft saved in the DEW barrier is less than the number of ships that must be added.
3. The combination airplane-ship barriers are more costly than pure airplane systems.
4. The ship has no influence in reducing force requirements in the DEW & C barrier.
5. If aircraft are spaced to take advantage of the ship's low altitude coverage, the value of the ship as a communication relay or navigation check point is questionable.
6. If aircraft are spaced to enable them to communicate and navigate with the pickets the number of aircraft in the system will, at best, be the same as those in a pure system.

In addition to the above considerations it must be realized that if a ship is assigned to, and is to be relied upon in, an early warning barrier, its usefulness in ASW is limited. On the other hand, if the picket has the authority to leave the line to follow up ASW contacts, then this airplane system must be capable of operating as a pure system.

APPENDIX D

SELECTION OF MAXIMUM CONTROL CAPABILITY FOR DEW & C AIRPLANE - INTERCEPTOR CASE

The amount of control incorporated into a DEW & C airplane should not exceed the maximum amount which might be required. For example, suppose that the defense setup is such that at most 80 interceptor passes are possible against a bomber raid passing through the control zone within a time interval equal to the interceptor recycling period. Then the control capability of a DEW & C airplane should not exceed that needed to control 80 interceptor passes on the worst possible type of bomber raid during the specified time limit. Any excess control capability would be unused and the DEW & C system cost would be increased.

The attainable number of interceptor passes depends on the velocity, spacings, and other tactics of the bomber raid. From the viewpoint,of causing control difficulties, the optimum bomber strategy appears to be that in which the raid is partly or wholly within the control zone for the minimum amount of time. This is accomplished by spacing the bombers for minimum raid depth, using a flight path which is in the control zone for minimum distance, and flying at maximum velocity. This optimum raid strategy furnishes targets to the interceptors for the shortest amount of time. Thus, the interceptors must make their passes in the minimum amount of time so that the control difficulties are maximized.

This appendix presents an analysis of several situations which appear to approximate, at least roughly, those anticipated for the time period when a DEW & C zone would be introduced. In this analysis, the bomber raid is assumed to adopt an optimum strategy of the type outlined above. The quantity determined is the minimum number of interceptors controlled as a function of the number of simultaneous interceptions which can be controlled.

ANALYSIS

Let us consider a line of DEW & C airplanes in which the control radius for each airplane is 140 miles. The spacing of the airplanes in this line is

such that any path through the line will be in the control region of the line for a distance of at least 190 miles (spacing of approximately 230 miles). The purpose of the line of DEW & C airplanes is to furnish controlled intercept information for interceptors whose mission is to attack bombers which enter the control region of the line. A line of DEW airplanes without control located several hundred miles in front of the DEW & C line furnishes information which allows the interceptors to begin attacking the bombers when they enter the control region. The attack on the bombers continues through the control zone and stops when the bombers leave this zone. An average of 5 minutes is required for each controlled intercept.

The bomber velocity is equal to V knots. This implies that any raid passing through the control zone is in this zone for at least (60) (190)V minutes. Let s be the number of simultaneous controlled intercepts that each DEW & C airplane is capable of handling. Thus, on the average, at least (60) (190)s/5V passes can be controlled by each of the DEW & C airplanes for any type of bomber raid. The values of V considered are 200, 350, 500 knots while the values of s are 12, 24, 48. For a velocity of 500 knots the average number of passes per interceptor, p(V), should not exceed 1.2 for the values of s considered. For V = 350 knots the value p(V) should not exceed 1.6 while for V = 200 knots this value should not exceed 2.

The above considerations show that at least (60) (190)s/5Vp(V) interceptors can be controlled to their full usage by each DEW & C airplane. The following table lists values of the quantity (60) (190)s/5Vp(V) for V = 200, 350, 500 and s = 12, 24, 48:

V	s	Minimum Number Interceptors Controlled
200	12	68
	24	137
	48	274
350	12	49
	24	98
	48	196
500	12	46
	24	92
	48	183

It is wasteful to provide control in excess of that needed for maximum usage of the available interceptors. Thus the value of s should never be such that $(60)(190)s/5Vp(V)$ exceeds the maximum number of interceptors available to attack a bomber raid in any 230-mile section of the control line.

CONCLUSION

Velocities exceeding 500 knots are not anticipated in the next few years. Consequently, if the maximum available number of interceptors per 230-mile length of the DEW & C line does not exceed 46 at one time, the control capability of the DEW & C airplanes should not exceed 12 simultaneous intercepts. Since the value 46 appears to be large for the presently anticipated defense postures, design of the DEW & C airplanes for a maximum of 12 simultaneous intercepts appears adequate.

LIST OF REFERENCES

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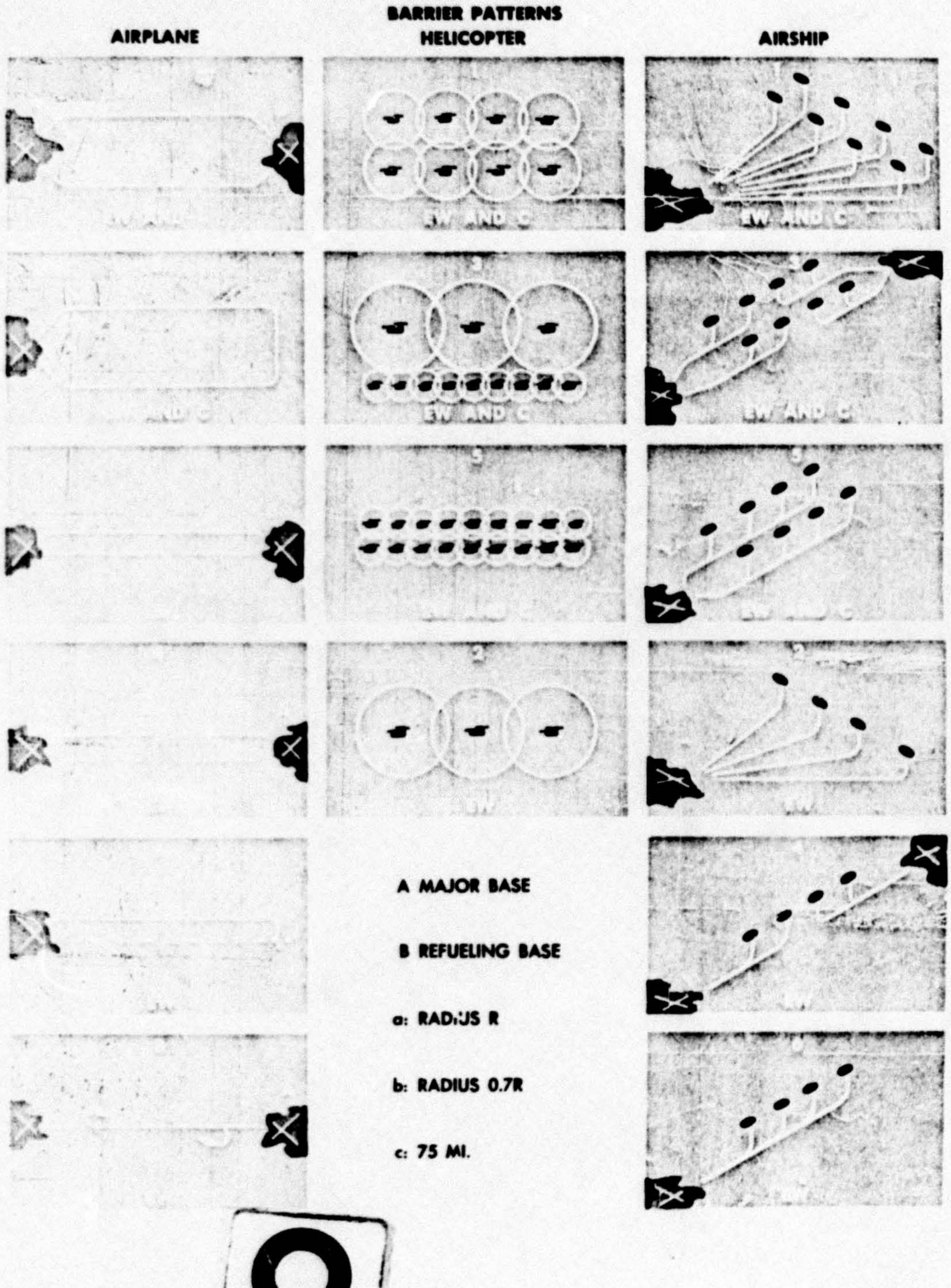
TERMS, SYMBOLS AND ABBREVIATIONS

AI	Airborne Intercept.
C_B	Cost of Bases, $ millions.
CIC	Combat Information Center.
C_{CVE}	Cost of CVE-class carriers, $ millions per year.
C_{HS}	Cost of all helicopters in the system, $ millions per year.
C_{IFP}	Cost of In-Flight Personnel, $ millions per year.
C_{ML}	Cost of Military Load, $ millions.
C_{MV}	Cost of converted Merchant ships, $ millions per year.
C/N	Cost per aircraft per year, $ millions.
C_S	Barrier system cost, $ millions per year.
D	Length of the barrier, n. mi.
DER	Radar picket ship, Destroyer Escort Type.
DEW	Distant Early Warning.
DEW & C	Distant Early Warning and Control.
ECM	Electronic Countermeasures.
h	Aircraft Altitude, feet.
I	Take-off interval between aircraft, hours.
k	Base location factor.
MTI	Moving Target Indicator.
N	Total Force Requirement – Total number of aircraft required to attain a certain level of detection.
N_t	Total helicopters required in system.
P_o	Operator Factor.
PPI	Plan Position Indicator.
S	Barrier spacing: The spacing between adjacent aircraft, n. mi.
T_c	Time required to climb to altitude, hours.
T_d	Time required to descend from altitude, hours.
T_{cd}	Time to climb to and descend from altitude, hours.
T_m	Total mission flying time, hours.
T_R	Transit Radius, n. mi.
T_s	Time on Station (Endurance), hours.
$\mathcal{V}$	Airship Envelop Volume, cu. ft.
W_c	Crew weight @ 200 lbs. per man.
W_o	Take-off weight, pounds.
YAGR	Converted Merchant ship carrying air search radars and control equipment.
ZI	Zone of the Interior (Continental U.S.)
ϕ	A utilization factor equal to the ratio of the number of hours flown in barrier operation to the number of hours per month.


BARRIER PATTERNS
AIRPLANE
HELICOPTER
AIRSHIP
EW AND C
EW AND C
EW AND C
EW AND C
EW
EW
A MAJOR BASE
B REFUELING BASE
a: RADIUS R
b: RADIUS 0.7R
c: 75 MI.